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CONTENTS

CRITICAL SPEEDS OF HIGH-SPEED MACHINERY

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Colin Reid obtained his degree at Imperial College. He spent seven years at AEL working on machinery noise problems and gas turbine development, followed by eighteen months at AOL in charge of the engineering work. Since 1959 he has been attached to the Scientific Adviser's Group in the Ship Department at Bath, where he has been concerned with mechanical engineering problems, particularly in the fields of hydrodynamic lubrication and machinery dynamics.

Abstract

This article summarizes the current state of knowledge about the prediction of critical speeds, for use in the design of high-speed shaft systems. The necessity to be able to distinguish between the potentially troublesome and the harmless criticals is pointed out.

Reference is made to an investigation conducted on the Rolls-Royce Olympus gas turbine, to work carried out by W. H. Allen on oil film flexibility, and to techniques developed by English Electric/AEI for predicting the behaviour of large multi-bearing shaft systems running above several critical modes.

Introduction

In the past, critical speeds of turbine machinery were calculated at the design stage on the assumption of rigid bearing supports. In order to allow for the lowering of the critical speed caused by bearing flexibility, the machinery was usually designed to have its lowest calculated rigid-bearing critical at least 30% above the maximum running speed. This practice generally gave acceptable results, but is not really representative of the actual state of affairs.

The type of fabricated support structure currently being used gives rise to a number of modes of vibration, which can react through the bearings on to the rotor, resulting in a multiplicity of natural frequencies of the combined system. The situation is further complicated by the effect of the bearing oil films, which can contribute both stiffness and damping. It is now clear that many machines have a number of 'critical speeds' in their running range, where 'critical speed' is used to mean a value of the rotational speed equal to a

natural frequency of the rotor/bearing/supporting structure system. Not all of these are necessarily troublesome. The problem, therefore, is to predict the criticals that are potentially troublesome, and to deal with these. This involves the prediction of vibration amplitudes.

A case in point arose during bench testing of the Rolls-Royce Olympus TM1 gas turbine. Here, a critical speed near the upper limit of the running speed range gave rise to unacceptably high vibration amplitudes, although it is clear that the engine must have run through at least one other 'critical' lower down the speed range, without trouble.

This article summarizes the current state of knowledge about such criticals and their prediction, as a reference for use in the design of high speed shaft systems.

Olympus Gas Turbine Investigation

(a) Summary of running experience

The early development running of the Olympus TM1 engine was marked by the occurrence of severe vibration of the power turbine rotor at speeds in the neighbourhood of the design full speed, 5660 rev/min. The power turbine rotor consisted of a shaft supported in two plain bearings, carrying a heavy turbine disc overhung at one end. A Metastream flexible disc coupling at the other end connected the shaft through a long torque tube and a second Metastream to the test brake.

The calculated rigid bearing critical speed was 6990 rev/min, *i.e.* 23% above the design full speed. By adopting the simple assumption of a constant stiffness spring at each of the two bearing supports (not necessarily of equal stiffness), it was estimated that two critical speeds were likely to occur in the running range, the lower being a predominantly conical mode (bearing supports vibrating in anti-phase) and the higher a cylindrical mode (bearings in phase).

The observed vibration was of a somewhat sporadic nature; onset of severe vibrations could occur quite suddenly, in some cases after a fair period of smooth running at a given speed.

The evidence generally pointed to a critical speed in the region of 5600 rev/min. There were also indications of a minor critical at 4800 rev/min. When the coupling and torque tube were replaced by a flywheel of equivalent mass, the vibrations were unaffected; the coupling and drive were thus eliminated as the source of the trouble.

Various measures were adopted to try to overcome the problem. These included running with different forms of anti-whirl bearing; ensuring that the rotor was in a good state of balance, including attention to the turbine disc attachment to the shaft; and fitting a flexibly-supported bearing at the coupling end. None of these measures eliminated the tendency to undergo serious vibration, nor was it altered when the entire pedestal was mounted on air-

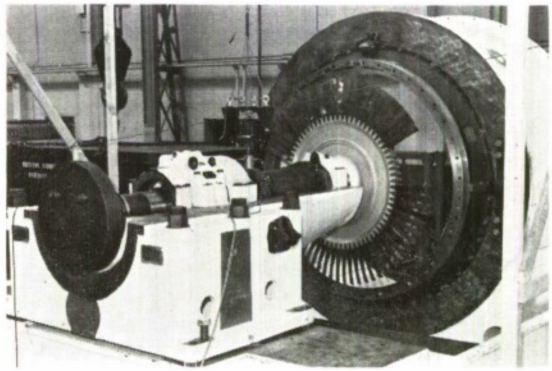

FIG. 1. *Olympus T.M.I.* power turbine on pedestal.

spring mounts. The trouble was finally cured by shifting the tail-end bearing so as to extend the bearing centres of the power-turbine rotor, thereby reducing the overhang of the drive coupling.

This change increased the calculated rigid bearing critical speed to 8470 rev/min, or 50% above the design full speed. Assuming support stiffnesses corresponding to the previously observed criticals, the first, conical mode, critical speed would still be expected to fall in the running range, although the second critical would now be safely above the maximum running speed. In the event, no serious vibrations occurred, although there was evidence of a minor critical around 4200 rev/min.

(b) Vibration Testing of the Olympus Power Turbine

(i) *Procedure*

In order to gain a clearer insight into the factors governing critical speeds, a series of vibration excitation tests was carried out by the Admiralty Engineering Laboratory (AEL) on the Olympus TM1 power turbine pedestal and rotor.

The structure was excited at a number of points successively, and the response at each point was presented in the form of a plot against frequency of the quantity (exciting force)/(displacement amplitude), *i.e.* the apparent stiffness. In addition to the driving point stiffness, the transfer stiffnesses to a number of other points were obtained. In some of the tests plots against frequency of the phase angle between force and displacement were also produced. Excitation in the vertical direction was employed in most of the tests. The power turbine pedestal and rotor, rigged for vibration testing, is shown in the illustrations.

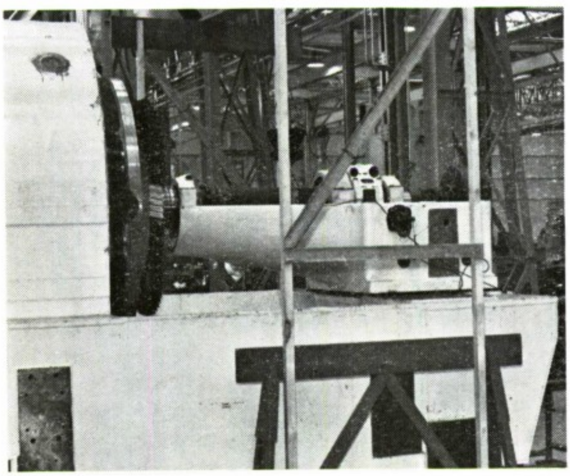

FIG. 2. Enlarged view of *Olympus T.M.I.* power turbine.

(ii) *Vibration of the support structure*

In the engine, the power turbine rotor is supported in two bearings attached to an anvil-shaped pedestal.

Tests on the structure alone, without the rotor, showed the apparent stiffness at the bearing positions to be very frequency-dependent over a frequency range corresponding to synchronous vibrations when running. Resonances occurred at 56, 65, 86 and 107 Hz, and at each of these the pedestal appeared to be rocking about a horizontal transverse axis near to its base. The motion of the bearings, therefore, was not independent —the motion at each bearing was influenced by excitation forces at both bearing positions.

(iii) *Vibration of the complete system*

Vibration tests on the complete system including the rotor showed four principal resonances in the frequency range of interest. These occurred at 50, 70, 90 and 117 Hz when the rear bearing was in its original position, and at 50, 70, 94 and 105 Hz with the modified rear bearing position. The resonances at 50 and 70 Hz were associated with mode shapes involving pedestal motion, the shaft remaining essentially straight. These were probably the 56 and 86 Hz modes of the pedestal modified by the effect of the rotor. The 90 and 94 Hz resonances were bending modes of the rotor, whilst the 117 and 105 Hz resonances involved both rotor bending and pedestal motion. These higher frequency resonances, involving rotor bending, had higher values of the quantity (displacement amplitude)/(exciting force) than the lower frequency resonances at 50 and 70 Hz.

(c) Natural frequency calculations

The Olympus power turbine natural frequencies were calculated using a computer program based on a development of the Prohl method for flexible rotors; the bearings were represented as constant stiffness independent springs. Two sets of calculations were performed, in which the gyroscopic effects of the turbine disc and shaft coupling were disregarded and included respectively, representing the non-rotating and rotating cases. The calculations showed considerable differences between the predicted natural frequencies and mode shapes; moreover, the differences would be further accentuated in practice by bearing oil film effects.

The experimental and computed natural frequencies, for both non-rotating and rotating cases, are shown in the accompanying Table.

It should be noted that:—

(i) for the rotating case, the experimental critical speeds were those observed up to 100 Hz, since the rotor was not run above 6000 rev/min.

(ii) In the computations, the assumed support stiffnesses were chosen to give critical speeds in accord with those observed with the original (56 in.) bearing span.

NATURAL FREQUENCIES IN Hz

	Non-rotating	*Rotating*
	56 in. bearing centres	
Experimental	50, 70, 90, 117	70, 80, 93
Computed	61, 90, 110	68, 95
	66·5 in. bearing centres	
Experimental	50, 70, 94, 105	70
Computed	61, 99, 135	69, 135

It will be seen that the calculations gave quite good agreement with the observed behaviour even though they were based on the assumption of simple spring supports, whereas the actual support structure was shown, in the static vibration tests, to respond to excitation in a complex manner. In particular, the calculations predicted the effectiveness of extending the bearing span in removing the troublesome critical at 93 Hz from the running range. The static tests, on the other hand, did not give an acceptable prediction of the behaviour when rotating—in fact in the static tests the longer bearing span had no better vibration characteristics than the original configuration. These tests did, however, indicate that vibration would be more severe in modes where shaft bending was involved.

Summary of Results Obtained by W. H. Allen

(a) Procedure

An investigation under MOD(N) sponsorship, was carried out by Messrs. W. H. Allen of Bedford into the influence of the bearing oil films and the bearing housing support system on the vibrational behaviour of a rigid rotor[1]. The rig used consisted of a small steam turbine rotor with its blades removed, driven through a gear tooth coupling by an electric motor. The rotor was supported in two oil-lubricated plain bearings. Each bearing housing, of relatively large mass, was supported by three axially arranged bars of circular section, cantilevered from a rigid base and equally spaced on a pitch circle around the bearing centre. Three alternative sets of bars were available whereby the stiffness of the bearing supports could be changed. The rigid bearing natural frequency of the rotor was above the maximum rotational speed of the rig. The rotor was deliberately unbalanced for certain tests.

Vibration measurements were taken by four inductance probes mounted on the bearing housing at the free end of the rotor. Two of these measured the journal displacement relative to the housing in two mutually perpendicular planes; the other two measured the housing displacement relative to the base.

At low speeds the vibrations were at synchronous frequency. As the speed was increased a point was reached where oil film whirl commenced. This was characterised by a large increase in the vibration amplitude and the appearance of a new fundamental frequency. The whirl persisted as the speed was increased beyond the onset speed.

(b) Synchronous vibrations

The experimentally determined journal and bearing housing vibrations below the whirl onset speed were compared with results obtained from a theoretical investigation. Vibration amplitudes were computed assuming excitation by a given rotor unbalance. (The actual rotor unbalance was measured in a balancing machine.) Each of the two bearing supports was treated as a simple mass on a spring with damping; the spring stiffness and damping coefficient were determined experimentally by vibrating the bearing housing alone, without the rotor, for each of the alternative sets of support bars. The rotor was considered to be rigid. The bearing oil films were assigned values for stiffness and damping in accordance with lubrication theory.

A good measure of agreement was obtained between the computed and experimental results. The running speeds corresponding to maximum values of vibration amplitude were well predicted, as also were the phase angles of the vibration with respect to the out-of-balance exciting force. Predicted values of amplitude at resonance were within 50% of the experimental values; the predicted values were, however, above the experimental values with very flexible bearing housing supports, but below the measured values with a stiffer housing suspension. Further calculations in which the bearing

oil films were taken as rigid showed that the main effect of the oil films was to attenuate the peak amplitudes—they had very little effect on the resonant frequencies.

In this particular case, therefore, it can be concluded that the vibrational behaviour can be quite readily predicted with a fair degree of accuracy. If the resonant frequencies only are required they may be calculated by considering the oil films as rigid. It should be noted, however, that the rig on which these results were obtained incorporated certain features which simplified the calculation procedure, but which are not found in most actual installations. These were:

(1) The form of the bearing supports (relatively large masses, cantilever supported).

(2) The stiff rotor, which could be considered rigid.

(c) Oil film whirl

This work also provided experimental data on behaviour under conditions of oil film whirl. It may be useful to mention the following points which were established:

(1) For a given condition of the rig, the whirl onset speed was consistent.

(2) The stiffness of the bearing housing supports had only a slight effect on the whirl onset speed.

(3) At any given speed and condition of the rig the whirl amplitude was constant and repeatable.

(4) The ratio of whirl frequency to rotational frequency was close to 0·5 at onset. This ratio was maintained with increasing speed until the whirl frequency coincided with the natural frequency of the rotor on its support system. The whirl frequency remained constant at this value with further increase in rotational speed. The frequency ratio ranged between slightly greater than 0·5 to as low as 0·23.

(5) Deliberate addition of unbalance caused the frequency ratio to be exactly 0·5 over the range where with a balanced rotor, it had been slightly greater or less than 0·5.

These observations are generally in accord with the theory advanced in[2] with the exception of (2) above. The insensitivity of the whirl onset speed to the natural frequency of the rotor/support system can be attributed to the very low static load on the bearings in these tests. The bearing oil films consequently ceased to be cavitated in the unloaded area at a fairly low speed, and this would be independent of the bearing support system. Oil film whirl developed when this speed was reached.

Summary of English Electric/A.E.I. Prediction Techniques for Large Rotors

(a) Procedure

Before their amalgamation, both the Mechanical Engineering Laboratory of The English Electric Co. Ltd. and AEI Turbine-Generators Ltd. had developed computer programmes for calculating the vibrational behaviour of large turbine-generators. These methods predict not only the various critical speeds of the system, but also the amplitudes of vibration that would arise at any given speed.

The method developed by English Electric is described here, but both methods are basically similar. The procedure is based on analyses of (1) the rotor, (2) the supporting structure, and (3) the bearings, and combining the three together in a mathematical model. The vibration of the rotor itself is treated as the sum of a number of normal modes. The supporting structure is also analysed into its normal modes by a finite element technique, in which it is divided into a large number of interconnected elements. Finally, the dynamic bearing oil film coefficients are computed by analysis of the oil film hydrodynamics for the particular bearing geometry under consideration. The response of the system is obtained for a number of values of the shaft rotational speed, assuming excitation by a particular unbalance distribution on the rotor. This might be the balancing machine residual, or, for large steam turbines, the estimated thermal unbalance, which could be an order of magnitude greater than the balancing machine residual.

The firm has stated that very good agreement has been obtained between the calculated and measured vibration levels for a number of large machines to which these methods have been applied.

(b) Practical difficulties

These methods are complex, and costly to apply, but are potentially capable of giving accurate predictions of vibrational behaviour at the design stage. The effectiveness of any proposed structural alterations in eliminating undesirable resonances can be determined. The main difficulty arises in allowing for the effect of damping in the structure. This adds considerably to the complexity; furthermore, the

magnitude of the damping terms to be incorporated can only be a rough estimate. The magnitude and configuration of the out-of-balance excitation to be used is also a matter of some conjecture.

Introduction of Flexibility and Damping: the Squeeze-Film Bearing

The power turbine rotors of gas turbines used in Naval propulsion are generally simpler in their support arrangements than the large land-based turbine generators for which The English Electric/AEI methods were developed. An approximate estimation of the location of the critical speeds can be made by assuming independent springs of constant stiffness at the bearing supports, and assigning estimated values to the spring stiffnesses.

A potentially dangerous critical evident at the design stage, or an actual serious critical encountered when running, can be removed from a part of the speed range where it is not acceptable by introducing flexible elements between the bearings and the main structure. Resonances will thereby be introduced lower down the speed range, and for this reason it is necessary to provide a damping device in addition to the added flexibility. Such a device is the squeeze-film bearing developed by Messrs. Rolls-Royce. The bearing is free to float radially in a narrow annulus filled with oil. It is essentially a damping device, and can be used on its own, as well as in conjunction with spring mounting of the bearings. A number of successful applications of the device have been made to aero engines. So far, they have been confined to rolling bearings only, and of these, the majority have been roller, not ball bearings.

Balancing

The amplitude of vibration at any speed will depend upon the excitation, *i.e.* the extent to which the rotor is out of balance. A high-speed rotor is always dynamically balanced in a balancing machine before installation. However, this operation is carried out at low speed, and only ensures that the rotor is balanced in its rigid-rotor modes. In service, the rotor may well be running at such a speed that it can no longer be considered rigid, and is quite likely to be out of balance in one or more of its bending modes, even though it was in balance when running in the balancing machine. By employing modal balancing techniques such as those described in (3), with the rotor running in its actual installation, it may sometimes be possible to reduce the vibration to an acceptable level. If the damping associated with each critical speed were sufficiently high, this procedure would be satisfactory. In many cases, however, the critical speeds have very low associated damping, and modal balancing would be unlikely to provide an effective long-term solution, since the slight changes in balance which inevitably occur during the life of the machine would be sufficient to cause large amplitude vibration at the critical speed.

Conclusions

(a) Methods are available for predicting the vibrational behaviour of high-speed machinery over its running speed range, and for assessing the effects of design changes introduced to eliminate unacceptable vibrational behaviour. These methods, however, are complex and expensive to apply, except for certain simple designs.

(b) There is evidence, at least for configurations similar to the Olympus TM1 power turbine, that a good estimate of the critical speeds and mode shapes can be made by a simplification whereby the bearing supports are considered as independent, constant stiffness springs. The allocation of stiffness values to these springs is mainly a matter of experience with similar machinery designs. Modes in which there is significant shaft bending must be considered dangerous.

(c) The bearing oil films have only a small effect on the critical speeds, but they reduce the peak amplitudes.

(d) Flexibly mounting the bearings, combined with the squeeze film damping device, has been effective, in aero engine designs, in shifting the criticals to the lower-end of the speed range, where they are not troublesome.

(e) Application of modal balancing, carried out on the actual installation at normal running speeds, may be effective in some cases.

References

[1] ASME Paper No. 69-DE-9, presented in May 1969. Assessing Unbalance Effects in a Small Turbo-Rotor, by R. Holmes and D. W. Parkins.

[2] A Theory of Oil Whip, by Yukio Hori. *Jnl. App. Mech.*, **26**, 1959, 189.

[3] Balancing of Large Turbine Rotors, by L. S. Moore. Trans. I. Mar. E., **81**, 4, April 1969.

MONITORING MACHINERY VIBRATIONS AND THE DIAGNOSIS OF FAULTS

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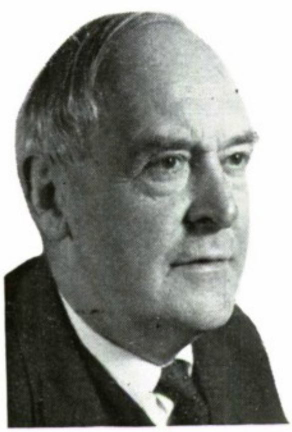

Leonard Le Page joined the Admiralty Engineering Laboratory in 1954. For some time before that he had been on loan from D.O.R. to the Ministry of Transport, engaged on Operational Research related to the introduction of the Decca Navigator System and commercial radar into the Merchant Navy. Whilst at the M.O.T. he proposed and contributed to "The Use of Radar at Sea" published by the Institute of Navigation, and now in its fourth edition. At A.E.L. he has worked on various aspects of machinery noise and vibration, and in particular has been closely associated with the development of acoustic cladding for diesel engines. He takes a keen interest in staff matters and is Vice-Chairman of the A.E.L. (Non-Industrial) Whitley Office Committee.

Abstract

The unexpected failure of any propulsion or auxiliary machinery in a warship can be a serious matter. The likelihood of this can be reduced by preventive maintenance, but this involves costly and time-consuming overhauls or replacements which may not prove to be necessary.

By measuring the existing levels of vibration on a machine, and comparing these with tolerable levels, the condition of the machine may often be established and early warning of trouble be given. More specific measurements can then be used to help diagnose the fault. Suitable instrumentation and experience in relating vibration levels and frequencies to the cause of trouble are however essential to success.

Introduction

This article is intended as a general review of the "state of the art" and makes no attempt to outline the work now being carried out in MOD(N), such as that being sponsored by the DG Ships Working Party on Non-Destructive Techniques. The monitoring of machinery vibrations is here taken to mean the determination of any changes of vibration in machines in normal usage, which may be indicative of wear, breakage or malfunctioning of the machine. The machinery particularly in mind is that typically fitted to conventional ships: propulsion and generator engines, pumps, compressors, motors and generators, etc. Monitoring is a routine process primarily intended to give a general warning that all is not well. Diagnosis is a further stage in which narrow band vibration measurements are used to help identify the cause of the fault, if one is indicated. It may not be necessary if the one-third-octave technique has been used for monitoring.

The vibrating surface of a machine will be affected by the whole spectrum of frequencies generated by the motion of all the parts in the machine, although measured levels of vibration will depend on the position at which the measurement is taken. Thus an understanding of the information, which is so generously and continuously supplied in the form of vibration, could be of great assistance in maintaining the machine in an efficient condition. Vibration monitoring and diagnostic instrumentation has a strong claim to be considered as more than an extra device which can be rather deprecatingly added to the existing array of thermometers, pressure gauges, speed indicators, and so forth; it does in fact have a unique position in view of the comprehensiveness of the information it can give. More widespread adoption of vibration monitoring as a performance and maintenance aid is to some extent held back by cost or apparent complexity of some instrumentation but mainly by a lack of precise knowledge as to how to interpret fully the data which is available. In addition, really complete systems, as opposed to measuring instruments alone, are required; and there would appear to be room for considerable improvement in this direction.

At the same time it would be unwise to suggest that even an ideal vibration monitoring system could supplant existing maintenance checks, and certainly not the practised eye which can immediately detect an unusual oil leak or a blown gasket. There are however many applications in which vibration monitors can well justify their cost, when for example machine failures involve high repair expenses, unacceptable periods of unserviceability, and, especially, risk to life.

Principles of Monitoring

Of those characteristic forced vibrations which are initiated by each moving part of a machine and transmitted through the body of the machine to its outer surface, the finger tips will detect very low frequencies if their amplitude is great enough, and with an upper frequency limit depending on the age of the observer a total range of touch and hearing from 2Hz to between 10,000Hz and 20,000 Hz may be covered. Certain manifestations of machinery ills, such as squeaks and rattles, are well adapted to human appreciation, and the senses should not be depised as monitoring aids, even bone conduction when contact is made with a judiciously placed screwdriver. Instruments present the advantage of being able to select, measure, allow the identification of frequency components, and permit quantitative comparisons over a period of time. They are therefore essential tools in the familiar philosophy of vibration monitoring, which is, that if vibration levels at a given position are unusually high, either with respect to an initial reference level or to an accepted standard, this state of affairs is an indication of some deterioration in the machine. Clearly it is of the greatest importance to establish a realistic tolerance; an excessive vibration which is shaking a machine to pieces will be evident to eyes and ears, and will eventually result in there being no vibration at all from that machine! The object of monitoring is to give early warning and prevent such disasters. In practice, a fairly substantial increase in vibration level is often acceptable before any corrective action is considered. Whether or not the contingency of increase in vibration level is the sole indication that deterioration has occurred is a matter which will be dealt with later.

Practical Considerations

It is well known that (Fig. 1) if the spectrum of vibration at a given point on a machine is analysed, it will be found that while white noise and low level components form a general vibration background, most spectra are mainly characterised by a number of outstanding frequency components. Many of these frequencies are determined by the running speed of the machine and by design characteristics such as the number of blades in an impeller or rotor, the number of teeth in a gear wheel, or the number of cylinders in an engine. The actual vibration levels at these frequencies and those of the background are governed not only by the design and quality of manufacture of the machine, but depend on several factors, including:—

(a) the manner of assembly of the machine, and its subsequent adjustment,

(b) the method of mounting the machine, notably whether it is on isolating mountings, and the dynamic response of the seating,

(c) the point of measurement of vibration, since this determines the transmission paths from the source of vibration; also the plane in which the vibration is measured,

(d) vibrations originating elsewhere, for example in a nearby machine, and conveyed through a structure or as airborne or fluidborne noise,

(e) the load on the machine; the effect being particularly noticeable when it is varying, for example as torque on the shaft of a ship propulsion engine during heavy weather,

(f) temperature, lubrication, etc., and

(g) the mechanical condition of the machine.

Thus careful elimination of misleading circumstances is essential if worthwhile information about the last item in this list is to be obtained.

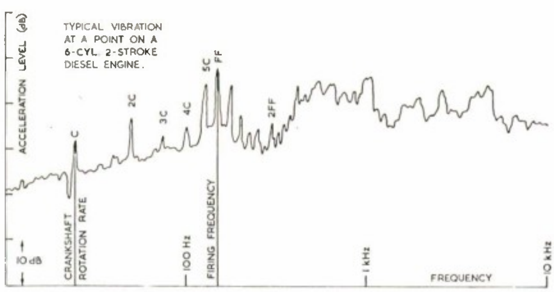

FIG. 1. A frequency spectrum measured with a narrow band analyser.

The problem is simplified if the running conditions observed during a previous reference measurement period are repeated as closely as possible. In this way, a diesel generator operating at constant speed and approximately the same load might be found to maintain day-to-day levels of vibration with a normal variation of no more than plus or minus 2dB over the greater part of the audio frequency spectrum. It is in fact of the greatest importance to ensure first of all that the normal variation when the machine is in good mechanical condition is reliably established.

Not all vibration measuring techniques are suitable for monitoring; on the other hand, monitoring has special requirements of its own. The choice of arrangements is wide; some of the possible alternatives are here presented in tabular form (Tables 1 and 2). The only comment that will be made here is upon whether acceleration or velocity levels should be preferred for indications. One examination of vibration measurements made on a substantial range of machinery showed that the spread of one-third-octave levels was much less for nearly all machines when displayed as acceleration rather than as velocity. Conversion to velocity emphasised the lower frequency bands (see example, Fig. 2). Thus for general monitoring, acceleration would seem to be preferable, but for monitoring which is restricted to the lower frequencies, velocity might be more attractive.

Units of measurement sometimes present a stumbling block. The ship's engineer may think of vibration in terms of peak-to-peak displacement measured in thousandths of an inch. The laboratory worker may have his instruments calibrated in rms acceleration in decibels with respect to a reference level of one milli-cm-per-sec.[2] A tolerance level of vibration may be specified in terms of velocity, or VdB. Reconciliation between all the options seems to be remote (but see ABC-Navy-Std-37A).

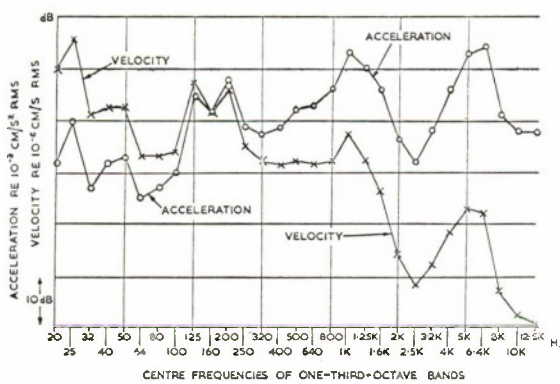

FIG. 2. Frequency spectrum of a water pump measured in one-third-octaves.

The Interpretation of Change

(a) *Vibration Monitoring. Specific faults likely to be indicated*

The following list is given of some specific faults which may be revealed by vibration monitoring. No doubt some items on this list could at some stage be detected by other means; a good watchkeeper on an automatic panel would note from symptoms such as lack of power, reduced oil pressure, increased fuel consumption, and so on, that all was not well. Vibration monitoring may however provide an earlier warning, and diagnosis by a vibration technique may help to confirm or refute a suspected cause.

(i) Static or dynamic unbalance or eccentricity; broken impeller or rotor blades.
(ii) Uneven firing.
(iii) Worn or damaged gears.
(iv) Worn or damaged bearings or bearing housings. Effects of fretting corrosion.
(v) Shaft becoming bowed.
(vi) Mechanical slackness or insecurity.
(vii) Loose or damaged belting.
(viii) Onset of cavitation.
(ix) Shafts becoming misaligned.
(x) Presence of solid bodies in a pump fluid.
(xi) Incorrect re-assembly after maintenance.
(xii) Absence of lubricant.

Monitoring is here considered to be a means of ensuring that the condition of a machine as fitted satisfactorily is maintained. It is not intended to reveal design weaknesses, but it is possible that it may in fact do so and thus lead to a permanent improvement.

There are two basic techniques of monitoring:

(i) Monitoring in the immediate vicinity of each selected part, *e.g.*, at each bearing, the warning level usually being specified in absolute terms. Graphs of acceptable vibration levels with respect to frequency have been established on the basis of practical experience. A portable instrument may be used.

(ii) Monitoring at one selected position on a machine, perhaps more on a large machine. This is less tedious than (i) above but is also less sensitive. Initial measurements to be used as a reference for the future must be made. A suitable monitoring position is just above a mounting on a resiliently-mounted machine.

In Fig. 3 is shown a prototype Spectrum Monitor into which the vibration levels from machinery in any one of five areas in a ship may be fed. A standard commercial accelerometer is screwed to an accelerometer block secured to a selected point on the machine under test. The accelerometer output is fed into a nearby impedance converter, the low impedance output of which is taken to a line amplifier of known gain. The line amplifier passes an amplified vibration signal (about one volt) to the main Spectrum Monitor which is installed in a convenient working compartment of the ship.

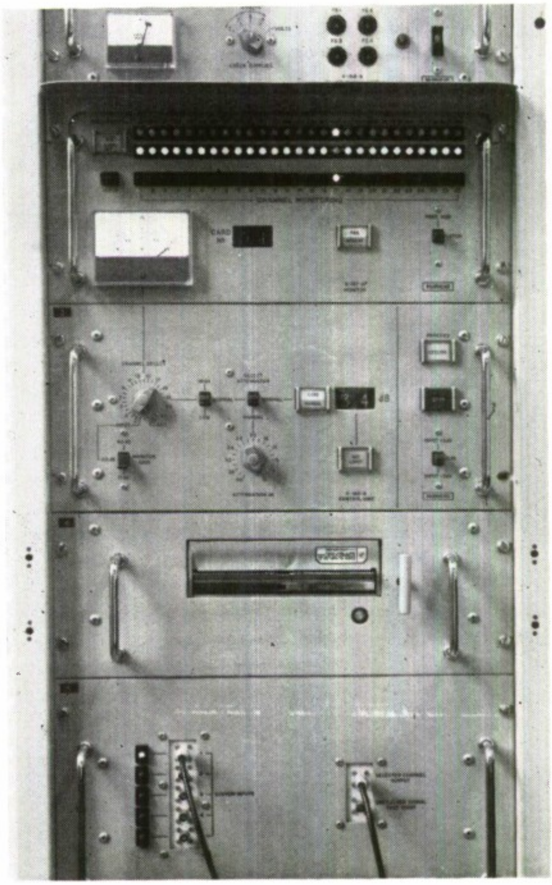

FIG. 3. A spectrum monitor for automatic vibration analysis. An excessive vibration level is indicated in the 400 Hz one-third-octave band.

The Spectrum Monitor analyses the incoming signal into consecutive one-third-octave frequency channels. (The prototype model is limited to 27 channels with mid-band frequencies from 10 Hz to 4 kHz.) A manually-prepared punched card, coded for the particular vibration test point and running conditions of the machine under test, is fed into the Monitor, and the start button is pressed. Subsequent operation is entirely automatic. If vibration levels throughout the measured frequency range are within the tolerances set up by the card, a green "Accept" indicator will be illuminated. Should however any level or levels fall outside the tolerances, a red "Fail" indicator, together with indicators marking the out-of-tolerance channels will be illuminated. The complete process now takes about 40 seconds, but this time could be at least halved. If some

abnormal vibration is indicated, further action can be taken to find the cause. The equipment will indicate either excessively high or unusually low levels of vibration.

One of the features of the system is its flexibility in respect of reference levels and tolerances. The tolerance levels in the Spectrum Monitor are set up by the punched card, and may be arrived at as follows:

Either:

(i) by measuring reference levels of vibration on the machine when it is known to be in good condition, and combining these levels with the allowable tolerances

or

(ii) by working to vibration levels specified for a class of machine, or to a recognised graph of acceptable levels.

It should be particularly noticed that if reference levels are used, different tolerances can be set up for different frequency bands. A tolerance of 6dB could be specified at shaft rotation rate to check out-of-balance, while 20dB could be permissible at say 4kHz to check bearing condition. (Octave bands up to much higher frequencies are desirable.)

No special skill is required of the operator in the main task of determining whether or not vibration levels fall within the set tolerance. Once a card has been prepared, no paperwork is involved, except perhaps a note to the effect that a test was carried out on a certain date, and a record of the result. Other facilities include that of continuous monitoring on one machine. It is not however intended for experimental investigations.

(b) *Diagnosis*

Since the discrete frequency components in a vibration frequency spectrum can usually be associated with the motion of particular parts of the machine, it is logical to expect a deterioration in that part of the machine to result in an increase of level in one or more of the related frequency components. This is in fact the case when imbalance is the cause: a damaged impeller or a broken turbine blade may be detected in this fashion. Some other types of fault, though, may produce rather different effects.

Consider a ball or roller bearing. Formulae may be calculated from first principles for the frequencies to be expected from bearings in acceptable mechanical condition, but which have minor irregularities inseparable from manufacture. Now a worn or damaged bearing will have the effect of modulating the waveform of the force transmitted from the shaft *via* the bearing to the body of the machine. It will also contribute a number of frequency components determined by the nature of the wear or damage. Hence not only will the 'expected' frequencies be likely to be masked, but any deterioration in the bearings would not necessarily be indicated by an increase in level of a frequency calculated from the bearing design. The observed vibration spectrum will however be markedly changed in some respect. Hitherto unobserved frequency components will appear, some of which may be due to excitation of natural resonances in the machine. Experience also shows that some frequency levels may decrease. Thus it would seem that it is *change* in the frequency spectrum, and not increase of level at expected frequencies, which is likely to be the more sensitive indicator of the nature of the fault. One way in which such change could be expressed in convenient form, if measurements are made in one-third-octave bands, would be to evaluate the variation of the new levels from the old.

Fig. 4(a) shows the difference in vibration levels between two similar shipborne extractor pumps, one of which was vibrating abnormally. Figs. 4(b) to 4(i) are selected examples from an investigation sponsored by MOD and carried out by Messrs. Vickers Ltd., in which common faults were applied to an electrically-driven fire-and-bilge pump.

Diagnosis, when necessary, is usually carried out with the vibration pick-up feeding a narrow-band analyser, using a band of say 1·2% or 5% of measured frequency. Other aids include a list of the frequencies likely to be generated in the machine; a C.R.O. display and audio output of the vibration signal; and a fair supply of experience. An accelerometer or velocity pick-up fitted with a probe and used as a stethoscope can be very useful, but indications must be treated with caution. Observation of a selected frequency or frequency band over a period of time can be helpful, especially when fault indications are intermittent. Indeed, fault conditions are often characterised by fluctuations or the occurrence of transients. In one investigation a continuous paper recording of the one-third-octave spectrum of vibration was operated by a velocity pick-up attached to the casing of a supercharger mounted on a diesel engine. Transient spikes began to appear in the one-third-octave frequency band containing

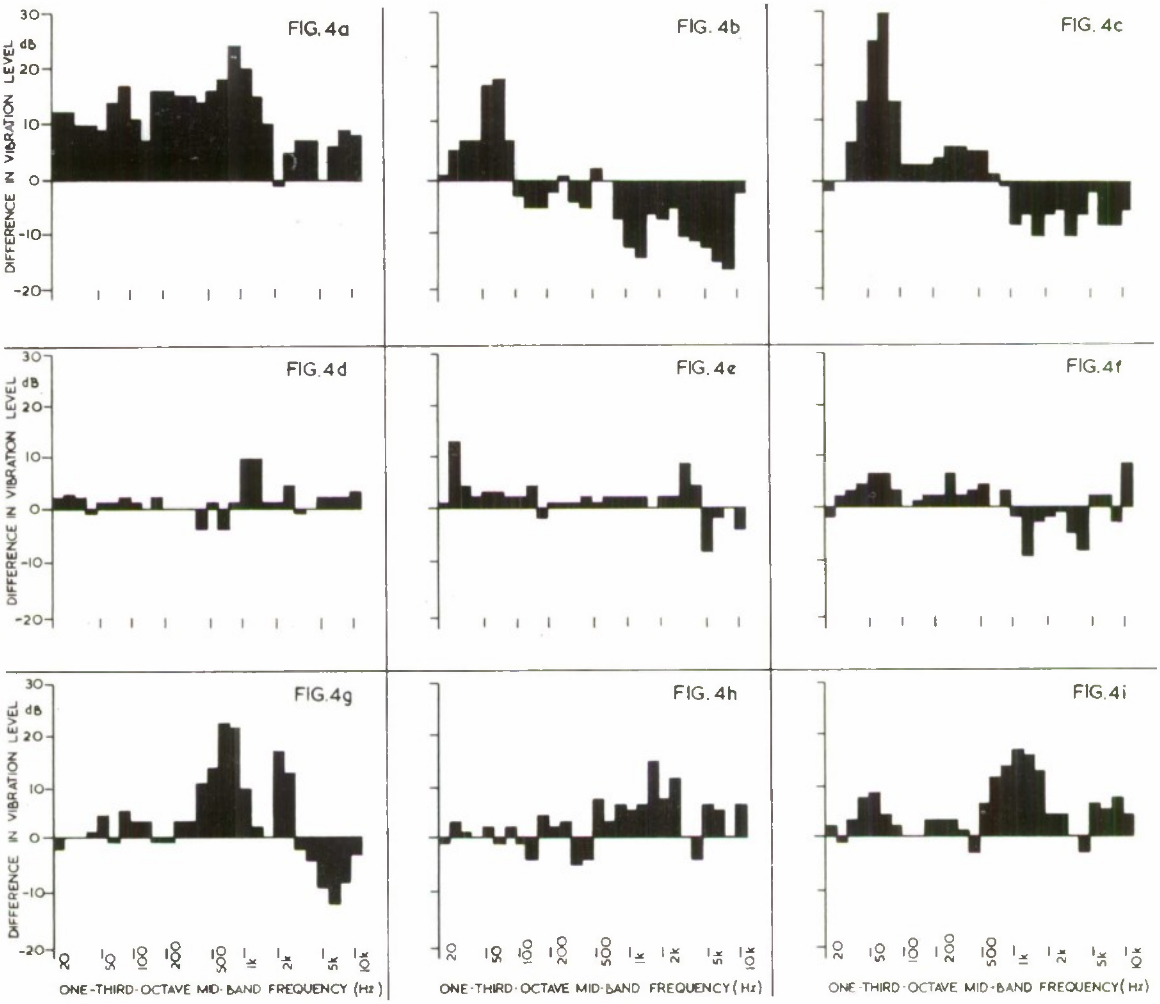

FIG. 4a. Ship's extractor pump, with turbine rotating in a worn bearing. Comparison of vibration levels with those measured on a similar pump in good condition at same speed and load. Considerable positive differences are apparent throughout the whole frequency range.

FIGS. 4b - 4i. Fire-and-bilge pump with various faults applied. Comparison of vibration levels with those made at same position with pump normal. Pump and motor shaft vertical. The unit was resiliently mounted.

(b) Broken motor fan blade. Vibration measured vertically, above mounting. An 18 dB increase in the band containing the component of shaft rotation rate is shown.

(c) As above, but vibration measured radially on ball race bearing end plate. The increase here is 30 dB, and as in 4(b) is accompanied by other changes including reductions at higher frequencies.

(d) Damaged roller bearing. Vibration measured vertically, above mounting. Changes, mainly increases, are apparent.

(e) As (d) vibration measured vertically on pump volute near roller bearing. The pattern is somewhat different from that of 4(d).

(f) Worn ball race. Vibration measured vertically, above mounting. Changes have taken place, but as much downwards as upwards.

(g) As above, but vibration measured vertically on ball race bearing end plate. Diagnosis revealed that the 22 dB increase in one band was due to a resonant frequency of the end plate.

(h) Scored outer track, ball race. Vibration measured vertically, above mounting. A positive increase is shown.

(i) As above, but vibration measured horizontally above mounting. The increases are very much more marked.

NOTE—Not all the one-third-octave bands have been marked. The full range of mid-band frequencies in the diagrams is as follows:—

20, 25, 32, 40, 50, 64, 80, 100, 125, 160, 200, 250, 320, 400, 500, 640, 800 Hz.

1·0, 1·25, 1·6, 2·0, 2·5, 3·2, 4·0, 5·0, 6·4, 8·0, 10kHz.

TABLE 1. Measurement Items and Requirements for Vibration Monitoring and Analysis.

Requirement	*Comments*
Vibratory Motion	
Vibration Velocity	Often expressed in dB re 10^{-6} cm/sec., rms or peak. Also in linear terms as mm/sec. Preferable for low frequency monitoring.
Vibration Acceleration	Often expressed in dB re 10^{-3} cm/sec.^{2}, rms or peak, or as a fraction of 'g'. Preferable for general use.
Vibration Displacement	Often expressed in mm or mils, usually peak-to-peak but sometimes as single amplitude. Inch measurements are also used.
Machinery Monitoring Points Above mountings if the machine is resiliently mounted. Near selected components of the machine, such as bearings and impellers. On the frame of electric motors and generators.	The pick-up may be mounted with the intention of measuring vibrations in the vertical, axial, or transverse plane, or radially with respect to a shaft.
Frequency Ranges 5 Hz to 100 Hz 5 Hz to 1 kHz 5 Hz to 10 kHz 5 Hz to 40 kHz	These ranges are only intended to be indicative of those normally chosen.
Frequency Band Widths Wide Band. Wide Band subject to low pass filters. Consecutive octave bands. Consecutive one-third-octave bands. Selected octave or one-third-octave bands. Discrete frequencies (say 5% or 1·2%). Selected discrete frequencies.	Generally, bands wider than those intended to identify single frequencies are mainly considered suitable for indicating rises in level. For diagnosis, the very narrow band widths are preferable. Lower and upper frequency limits will depend amongst other factors on the type of pick-up employed.
Vibration Levels Expressed as acceleration:— Minimum required to be measurable, 0·001 g. Maximum required to be measurable, 10 g.	These figures, representing a range of 80 dB including an effective tolerance, are much dependent upon the application.
Criterion of Degree of Deterioration Absolute level of vibration measured at a point near the machine component which is under observation. Increase in level from the reference level measured when the machine is believed to be operating satisfactorily. Summation of changes in level from the initial reference level.	More easily applied to diagnosis than to monitoring, unless numerous points can be checked each time. More suited to monitoring in circumstances in which a whole machine has to be monitored from one point only, for a wide range of faults.

TABLE 2. Instrumentation and Techniques Suitable for Vibration Monitoring and Diagnosis.

Instrumentation or Technique	*Comments*
Pick-up Transducer for Converting Vibrational Motion into Electrical Signal	
Electro-magnetic velocity pick-up.	May be affected by strong magnetic fields, but can be shielded. Is usually large and has an upper frequency limitation which may not be acceptable in some applications.
Accelerometer, usually with a quartz, barium titanate or lead zirconium titanate crystal.	Is compact and shock-resistant. Type is dependent upon requirements in respect of sensitivity, upper frequency, and temperature of environment.
	Output expressed in velocity or displacement may be obtained by using an integrating circuit at some stage in the system.
	Electrical isolation of the sensitive elements inside the accelerometer casing avoids earth loops.
Attachment of Pick-up to Machine under Test	
Pick-up is hand-held, making mechanical contact with machine by means of a probe.	Useful for diagnosis; less satisfactory for periodic monitoring, or where space is limited.
Pick-up is held with a magnetic clamp.	Upper frequency is severely limited by contact resonance; unsuitable for surfaces which are curved or non-ferrous.
Pick-up is affixed with plasticine or like material.	Satisfactory for certain applications; limited in respect of upper frequency by level of acceleration and temperature.
Pick-up is screwed to machine or into a metal or other rigid block firmly attached to the machine.	The best method. A block if used may itself be screwed to the machine or affixed with Araldite, etc. A number of blocks may be affixed at suitable positions.
Selection of Monitoring Point	
Pick-up transferred by hand from one machine or monitoring point to the next.	Tedious and time-consuming when pick-up has to be screwed in, but needs only one pick-up and spares.
Built-in system with fixed pick-up at each monitoring point and cables from each, selection being carried out either at machine or in monitoring control room.	Cost of pick-ups and cabling may be considerable, but is extremely convenient.
F.M. telemetry transmission from each machine to a receiver in the machinery space.	Could avoid use of cable, at the cost of other complexity. Not yet tried, as far as is known.
Reception of Accelerometer Signal	
Cathode follower or solid state impedance converter, thence into a pre-amplifier.	Instrument next to accelerometer must be connected to accelerometer by a cable limited to a few feet in length.
Charge amplifier.	Allows a considerable length of cable to be placed between it and accelerometer.
	Accelerometers are obtainable with built-in electronics with low impedance output.

TABLE 2. Continued.

Instrument Indicating the likely Existence of a Fault, i.e. *monitoring without diagnosis*	
Octave band, one-third-octave band, or selected band frequency analyser with meter read-out.	Suitable for a small number of monitoring points. Time-consuming, but useful for investigational work.
As above, with paper recording of output for comparison with a reference transparency.	Suitable for a moderate number of monitoring points. Time-consuming, as above.
As above with digital read-out or print-out.	As above.
Analyser with reference levels and tolerances which can be set up by hand or by means of a punched card; can have warning lamps to indicate when a tolerance has been exceeded, or when a set level has been reached.	Very suitable for routine testing on a go/no go basis. Paper work is reduced to a minimum.
Note The data from the pick-up can either be passed on-line to the analyser, or a portable tape-recorder can be used for gathering information consecutively from a number of machines, for later analysis.	
Instrument for Diagnosis	
Discrete frequency analyser with meter, paper recording, or digital print out. A C.R.O. display and audio output are advised.	Time consuming if a wide frequency band is to be examined.
Continuous on-line display on cathode-ray oscilloscope of the frequency spectrum.	Eminently suitable for assisting diagnosis by conventional methods. Expensive.
Analogue data digitised and fed into computer.	With sufficient practical experience derived from actual faults, the stage could be reached at which the fault can not only be diagnosed but maintenance instructions can be given.
Noise-print frequency spectrum versus time print-out.	A research technique which could be adapted to diagnosis, being particularly useful for transients.

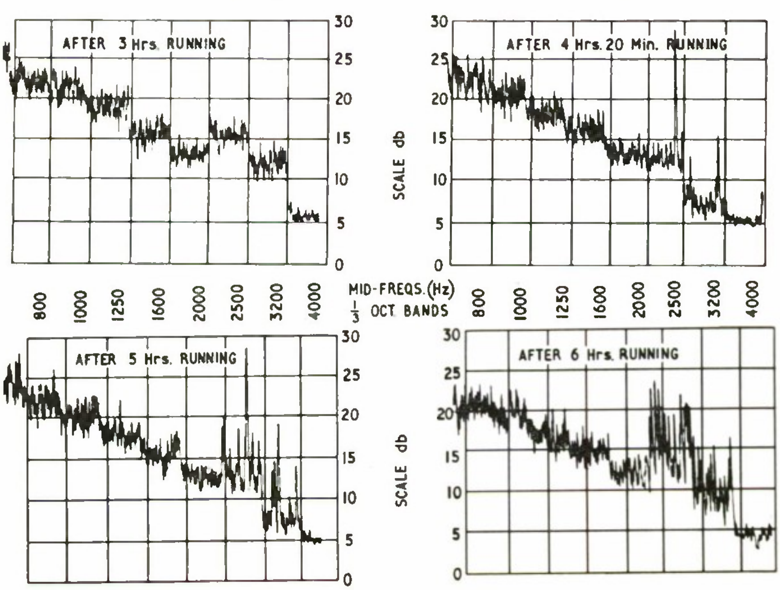

FIG. 5. Relative vibration levels (Velocity) near bearing on centrifugal supercharger.

a significant gear tooth frequency. These became progressively more apparent, and an increase in peak levels to 15dB above mean occurred in 5 hours. Examination showed that a roller bearing in the fluid drive had a greater clearance than that specified and was of a different type from the agreed standard, and that slip was occurring between it and the housing. The bearing was replaced and the trouble ceased. (Fig. 5).

A limited amount of information has been published on the subject of diagnosis, but much of this is descriptive of the vibrations observable from machinery parts in good condition, rather than of fault indications. The requisite knowledge can only be accumulated from theory, examination of machines exhibiting vibration changes, and the deliberate introduction of faults in controlled experiments. In this latter field very little appears to have been done commercially; one difficulty which is quickly found is that unless every precaution is taken to re-assemble a machine in precisely the same manner, the variation merely due to assembly can largely obscure the effect of many kinds of fault.

Diagnosis by computer would seem to be a logical step, but for this to be really worth while a comprehensive study of the mechanism of faults is needed, and detailed data concerning the parameters of the machine and its running conditions will have to be available.

Observations may be more readily interpretable when not obscured by the presence of natural resonances in the machine; applied damping, particularly in the neighbourhood of the pick-up, might lead to a partial improvement.

Conclusions. Methods of monitoring and of diagnosing faults in machinery are available and are improving. Instrumentation is adequate but requires to be embodied as a system directed towards a particular end. There appears to be a need for a collated body of objective information based on theory and directed experiment which will allow faults to be diagnosed reliably and quickly.

Acceptance of vibration monitoring as a serious technique by the use of which maintenance effort can be considerably eased, should encourage manufacturers to make provision for it in the design stages of a machine.

Acknowledgements

The author wishes to acknowledge the collaboration of his colleagues, in particular J. E. Holton (now retired) who proposed the Spectrum Monitor described herewith; F. Corben, who has done a great deal of analysis; W. Phizacklea and staff of Vickers Research; and others with whom there has been uninhibited discussion of the best means to achieve a mutually agreed aim. The views expressed are those of the author and do not necessarily represent the official attitude of DGS or AEL.

References

Handbook of Noise Control. Ed. C. M. Harris.

The Measurement and Suppression of Noise with special reference to electrical machines. A. J. King, 1965.

International Research and Development Corporation Instruction Manual — Vibration Analysis and Dynamic Balancing.

New Vibration Standards for Maintenance. Blake, Hydrocarbon Processing and Petroleum Refiner, January, 1964.

Aircraft Maintenance Costs Reduced by Jet-Engine Vibration Monitor, Barber, Instrument Practice, January 1964.

Noise and Vibration in Rolling Bearings. Clarke, Environmental Engineering, March 1967.

Vibration Analysis in Machinery Maintenance. Chapman, Naval Engineers Journal, June 1967.

Survey of Piezo electric accelerometers. Yarnold, Environmental Engineering, July 1967.

Noise analysis, a maintenance indicator. Bowen and Graham, Mechanical Engineering, October 1967.

Vibration monitoring on jet engines. Hatschek, World Aerospace Systems, February 1969.

Vibration Testing. Tustin, Machine Design, 29 May, 12 June, 26 June 1969.

Automatic Diagnosis of Engine Ailments. Hirsch, Electronics, 2 May 1966.

Acoustics as a Diagnostic Tool. Nuclear Energy Group Conference, Institution of Mechanical Engineers, 20 October 1970.

Machinery Fault Diagnosis from Vibration Spectrum Analysis. Vickers Research Ltd. Interim Reports, 1967 et seq.

Reference Values for use in reporting Mechanical Vibration Levels. ABC-Navy-Std-37A, 6 August 1970.

A FLUIDIC SYSTEM FOR DIESEL GENERATORS

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This article is based on a paper presented by the Author in collaboration with J. C. H. Davis and J. Kiraly of the Plessey Co. Ltd., to the Institute of Marine Engineers in November, 1970.

Abstract

A new design for a Diesel generator automatic starting and protection system that uses fluidics for the logic is described. Its function is to operate and check various quantities, then start the engine after first priming it with oil. When the engine is running, various parameters are sensed and should any reach pre-set limits, a warning and then an alarm is indicated. An alarm condition automatically shuts down the set.

The first three pre-production systems are fitted in H.M.S. Bristol *for evaluation at sea under service conditions.*

Introduction

Fluidics was born in the U.S.A. in 1959 and its potential as a method of control in tough environments was soon recognised. As with semi-conductor electronics, however, it has taken about 10 years to develop reliable and moderately priced devices and a suitable range of peripheral equipment to allow its widespread application to begin.

Many types of devices have been developed but the most popular and those used in the present system are based on the "momentum interaction" effect and on an effect discovered about 1911 by Henri Coanda. Fig. 1 shows how the Coanda effect causes a jet of fluid to be diverted towards an adjacent wall which, by preventing the entrainment of a free jet, causes a partial vacuum. Fig. 2 shows the main features of a practical device provided with a wall on either side of the power jet and with control and output ports. The jet will stick to whichever wall the control inputs deflect it and provide pressure at the appropriate output port until a countermanding control pulse is provided. The device is therefore bi-stable and acts as a memory.

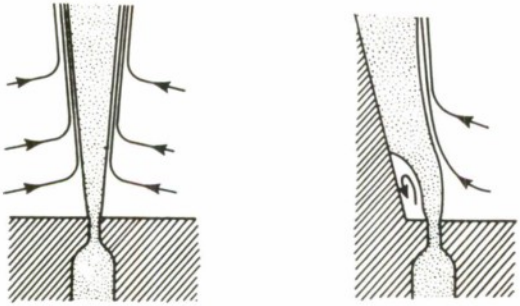

FIG. 1. Coanda effect.

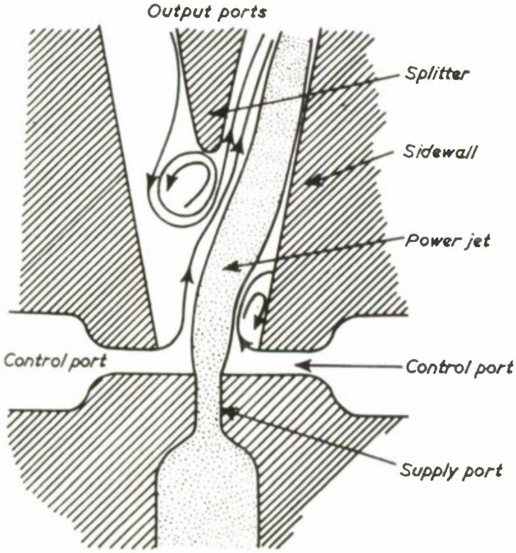

FIG. 2. Fluidic bi-stable.

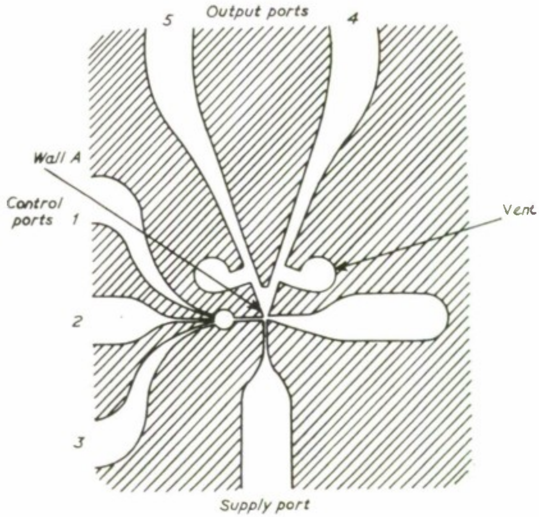

FIG. 3. Fluidic "OR/NOR" gate.

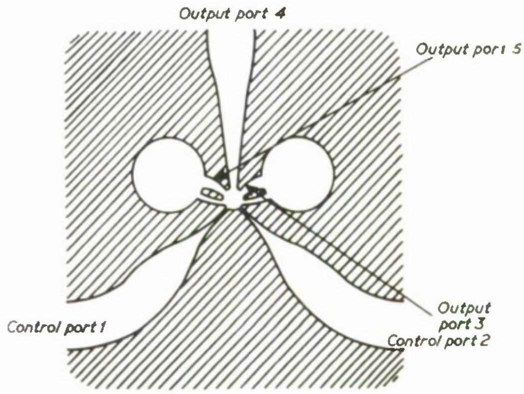

FIG. 4. Fluidic "AND" gate.

Fig. 3 shows a device similar to the bi-stable but modified to make the jet stable only along wall A. If a control input is applied to control port 1 OR 2 OR 3 the jet is deflected to give an output at port 4, known as the OR output. When these inputs are removed, *i.e.* when there is an input neither on port 1 NOR port 2 NOR port 3, the jet reverts to its stable state and provides pressure at port 5, known as the NOR output. Complex logic systems can be built up using this OR/NOR gate and the bi-stable, both of which provide moderate power amplification.

Fig. 4 shows a device based on momentum interaction. The walls are designed so that the Coanda effect is prevented. A control input at port 1 alone produces a jet which traverses the centre of the device in a straight line and merges from port 3 where it may be vented. Similarly a control input at port 2 alone emerges from port 5. If inputs are present at port 1 AND port 2 simultaneously the jets collide in the central region and emerge from port 4. This device is therefore a very simple AND gate. It has no separate power supply but inevitably causes a signal power loss.

Such devices will work over a wide range of supply pressures, and within the working pressure range their properties result primarily from their mechanical shape. They will therefore work in almost any environment if made in a material which will withstand it mechanically. They can be unaffected by temperature over 1000°C (1832°F), by nuclear radiation

and by high levels of shock and vibration and can be made in metals or ceramics. At the other end of the range they can be injection moulded and are therefore potentially very cheap to manufacture for use in less rugged applications. While compressed air is the normal power source they can work with any gas and all but the most viscous liquids.

The devices necessarily consume power all the time but the consumption is being reduced to a level which would be acceptable to almost all users. The lack of good interfacing devices is being remedied and fluidics generally interfaces better with pneumatic or hydraulic mechanical techniques than does electronics. The only important fundamental hazard is in most applications the possibility of partial or complete blockage of the passages by dirt. Good devices can withstand quite large amounts of dirt and elementary precautions are all that are normally necessary to give long life. If necessary the devices can be made as good as new by cleaning.

Some areas in which fluidics are being applied are missiles, aircraft jet engine controls, governors, machine tool controls, controls in areas with fire or explosion hazards, servo systems and medical respirators.

Application

H.M.S. *Bristol* a new guided missile escort destroyer will enter into service in the early 1970s with the first of a new design of sequential starting and surveillance system fitted to the diesel generating sets.

This design has incorporated to a great extent the new techniques of fluid logic control interfacing with conventional pneumatics and electrics. From the early stages of design the intention was to build a system that utilized low pressure fluidics air for any short distance control and an electrical d.c. power supply to relay signals to remote positions.

The feasibility of using fluidics in such a system was first evaluated in an experimental system using discrete components. The results from this were sufficiently encouraging to enable work to proceed to the next stage of building an engineered prototype, before producing three systems for trials in H.M.S. *Bristol* prior to their introduction as standard naval equipment in the new Type 42 Destroyer.

Having an operational system at sea will have concluded a three-year programme to provide a control system designed to overcome many problems associated with the extreme environment found in a ship's machinery space.

System

The system consists of three units together with auxiliaries that are grouped as follows:

1 a local start/stop unit incorporating the bulk of the fluidic circuits, interface valves and visual indicators;
2 an engine mounted surveillance unit containing the fluidic integrated circuit, interface valves, sensors and indicators associated with the monitoring of the engine; various gauges are also mounted on the panel for convenience;
3 a remote unit to give start/stop facilities and indication of engine state;
4 sensors for detecting valve position, fluid pressure, fluid temperature, fluid level and rotary speed;
5 pneumatically operated valves and actuators.

Automatic Starting Sequence

The schematic diagram in Fig. 5 shows the basic engine layout while the flow diagram (Fig. 6) illustrates in detail the sequence of events occurring after initiating the engine start from either the machinery space or the machinery control room. The output signals to the various valves and the visual indication on the systems start/stop surveillance and remote units are shown in Tables 1 and 2.

After pressing the start button the system is primed with air and a number of valves controlling the engine's auxiliaries are opened. This is followed by an automatic check on the items listed in Table 3 as the pre-start checks. Should any of the pre-start check conditions be incorrect, the specific fault or faults are indicated on the start/stop unit. Any of these faults with the exception of low lubricating oil level will inhibit the start, until the fault is cleared. The only position available for detecting the oil level in the sump made the level inherently affected by the ship's roll. Had this pre-start check inhibited the start, an automatic start would be impossible under heavy sea or permanent list, so only a visual indication and warning is provided.

When all the pre-start check conditions are satisfied or the faults cleared the starting sequence proceeds automatically with the priming of the lubrication system. Upon satisfactory pressure being reached in a set time, the air to the engine's air operated starter is switched on and the engine is turned for starting.

Failure of the engine to fire and reach a self-sustaining speed within 10 seconds results in the closure of the starter air valve for 20 seconds.

Once the engine is running normally at 1200 rev/min the surveillance unit automatically takes over and all unwanted air supplies are switched off to conserve air.

Three attempts are made to start the diesel generator set before a "fail to start" is indicated.

TABLE 1.

System Outputs
Open Sea Water Inlet Valve.
Open Sea Water Outlet Valve.
Open Fuel Oil Valve.
Run Lubricating Oil Prime Pump.
Run Start Motor.
Hold Off Governor.
Break Contact Breaker.

TABLE 2.

System Indications
Fluidically:
All Fault Conditions in Table 3.
Electrically In M.C.R.:
Remote Control Available
Engine Running
Low Fuel Oil Warning
Warning Level Fault
Alarm Level Fault
On Dial Gauge:
Lubricating Oil Pressure
Lubricating Oil Temperature
Cooling Water Temperature
Generator Air Temperature
Engine Speed
Supply Air Pressure

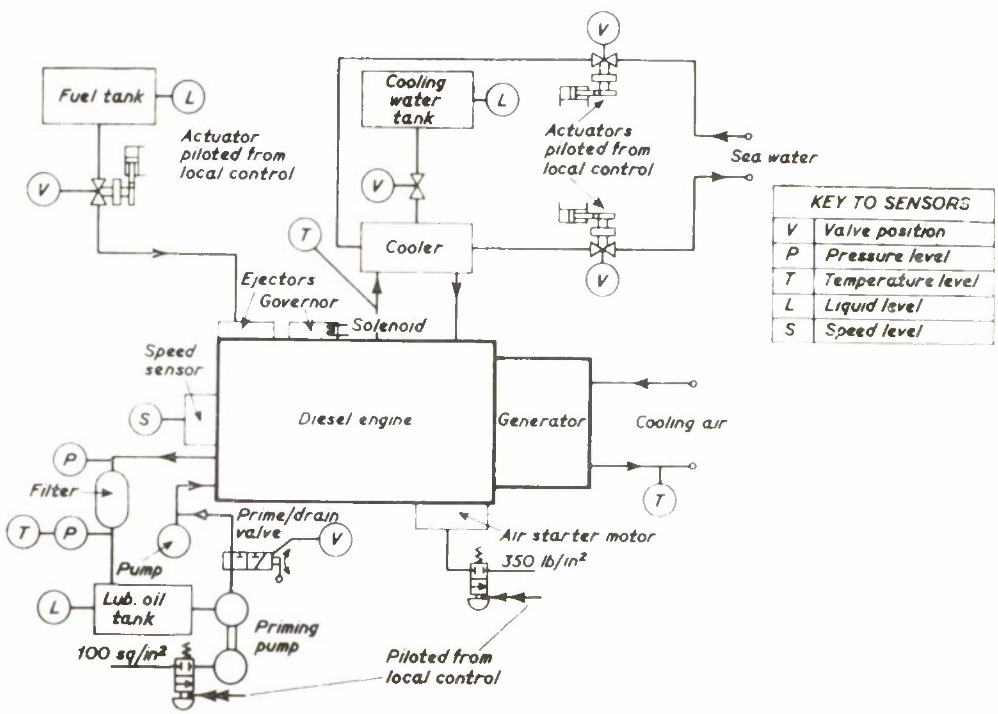

FIG. 5. Diagrammatic arrangement of system.

TABLE 3.

System Sensor Inputs

Function	*State or Limit giving the 1 (correct) Condition*	*Where Used*	*Remarks*
Sea Water Inlet Valve	Open	Pre-Start Check	
Sea Water Outlet Valve	Open	,,	
Fuel Oil Valve	Open	,,	
Fresh Water Circulating Valve	Open	,,	
Prime Drain Valve	Prime Position	,,	
Lubricating Oil Sump Level	Above Minimum Level	,,	'O' Does Not Inhibit Start
Fuel Oil Tank Level	Above 20% Full	Pre-Start and running check	Running Check warning only
Cooling Water Tank Level	Above 20% Full	Pre-Start Check	
Lubricating Oil Pressure	Above 2 lb/in^{2}g	Start Sequence Check	Enabled after 15 secs
Engine Rotation Speed	Above 315 rev/min	,,	'Start Fail' indicated if 'O' after 3rd start attempt
Lubricating Oil Pressure	Above 30 lb/in^{2}g	Surveillance	Warning Level
Lubricating Oil Temperature	Below 96°C (205°F)	,,	,,
Fresh Water Temperature	Below 85°C (185°F)	,,	,,
Generator Air Temperature	Below 70°C (158°F)	,,	,,
Nominal 80 lb/in^{2}g Air Pressure	Above 70 lb/in^{2}g	,,	Not interlocked with logic
Lubricating Oil Pressure	Above 25 lb/in^{2}g	,,	Alarm Level
Lubricating Oil Temperature	Below 99°C (210°F)	,,	Alarm Level
Fresh Water Temperature	Below 88°C (190°F)	,,	Alarm Level

Surveillance

During engine running the surveillance units monitors five quantities, three of them at both warning and alarm levels as detailed in Table 3. Four of the quantities at warning level and the three alarm levels are inter-locked fluidically as follows: in the absence of an alarm, all warning level indications appear and disappear as the respective quantities vary outside and within limits. When an alarm first arises all of the four interlocked warning indications are locked into their existing states and any subsequent alarm indications are inhibited. This allows the state of the engine at the time the alarm occurred to be noted without confusion from later events, such as the drop in lubricating oil pressure, inevitable when the engine stops.

When an alarm is detected it initiates the alarm-stop sequence. The existence of an alarm and/or warning level fault is indicated electrically at the remote unit.

Alarm-Stop Sequence

The main results of an alarm being detected are shown in Fig. 7. In order to minimise the air consumed during surveillance and to avoid duplicating timing circuits already available in the start/stop unit, the latter is re-powered to perform the alarm-stop sequence. Irrevelant parts of the logic are inhibited by " alarm bias " provided from the conventional pneumatics.

It is necessary to stop the engine by continual excitation of the governor solenoid and stop excitation only when it is certain that the engine is stationary and will not therefore restart itself without protection. It has been found that 70 seconds is needed to guarantee this with the lowest conceivable bearing friction and the highest inertia. When this time has elapsed it is safe to shut off the sea and fuel valves, but the supply to be fluidics is maintained until the stop button is pressed to allow all indications to be noted. Pressing the

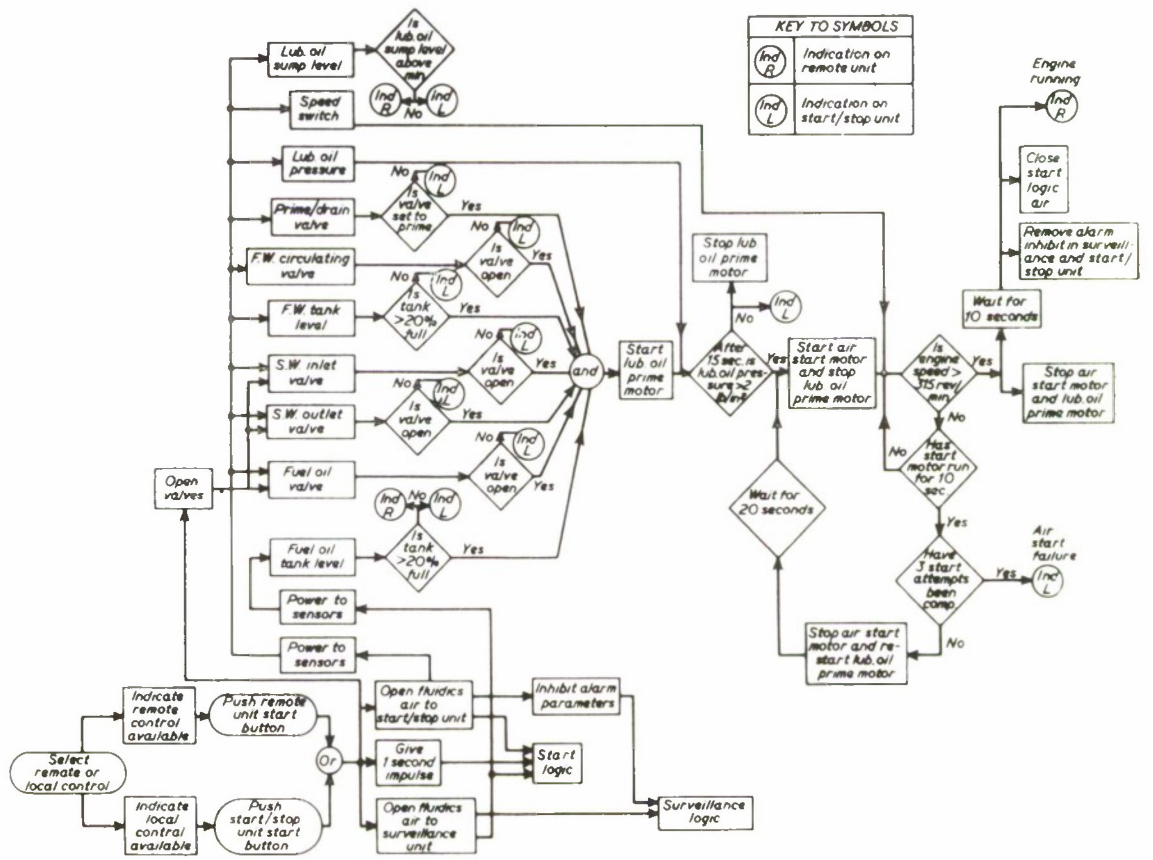

FIG. 6. Start sequence flow diagram.

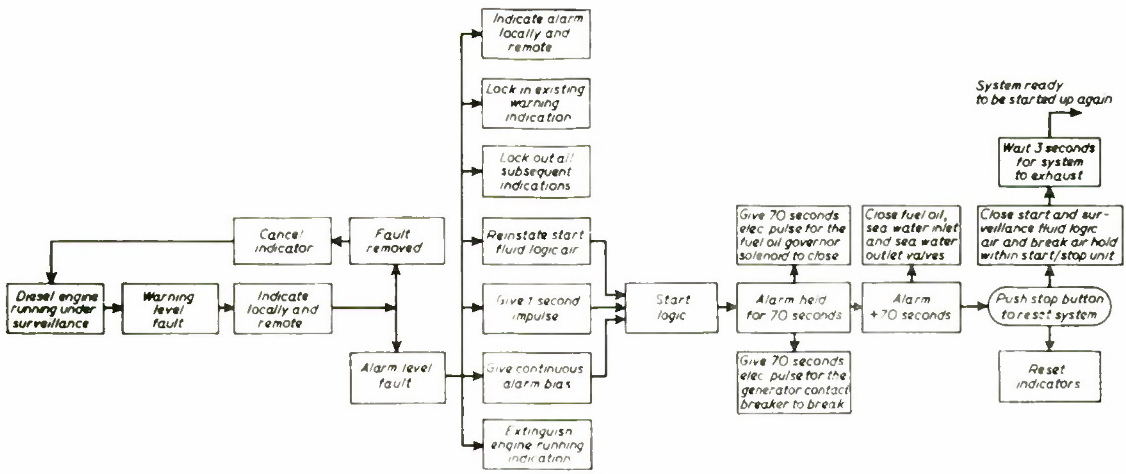

FIG. 7. Warning and alarm stop sequence.

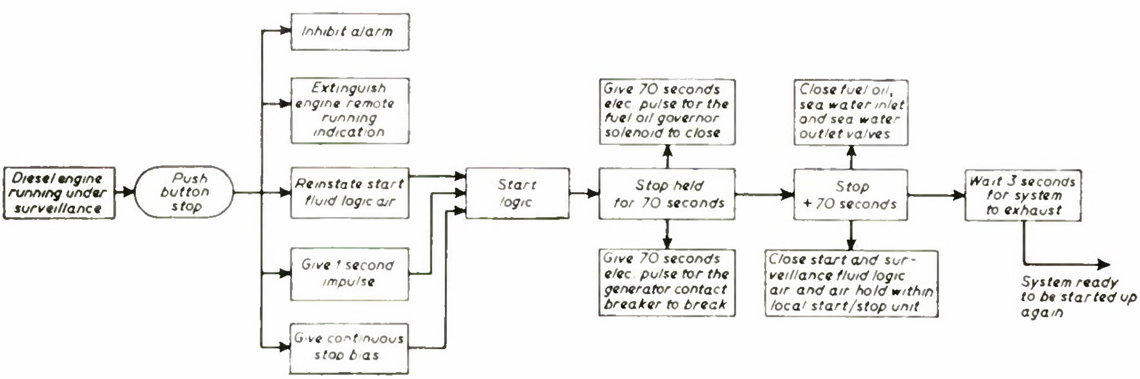

FIG. 8. Non-alarm stop sequence.

stop button switches off the supply to the fluidics and resets the system to its quiescent state.

If the stop button is pressed before the end of the 70 seconds, resetting does not take place until the full time has elapsed.

Non-alarm Stop Sequence

The normal, or non-alarm stop sequence, shown in Fig. 8 has many features similar to the alarm-stop sequence already described.

It is initiated by pressing the local or remote stop button, which results in the start/stop unit being re-powered and irrelevant circuits being inhibited by "stop bias". The governor solenoid is energised for 70 seconds to stop the engine after which the system returns to the quiescent state. No specific signal to close the valves is needed in this case as the removal of power from the fluidics automatically gives the signal.

Fluid Logic

Once fluidics had been chosen to perform the more complex control functions it was logical to use it as extensively as possible. The boundaries were set by the following considerations.

(1) to reduce the need for radically new sensors these would in most cases be conventional mechanical devices (*e.g.* gauges) with back pressure sensors or jet collector systems providing control signals to the fluidics;

(2) fluidic devices are inefficient as power amplifiers so all amplification above normal logic levels was done by pneumatic step-up relays;

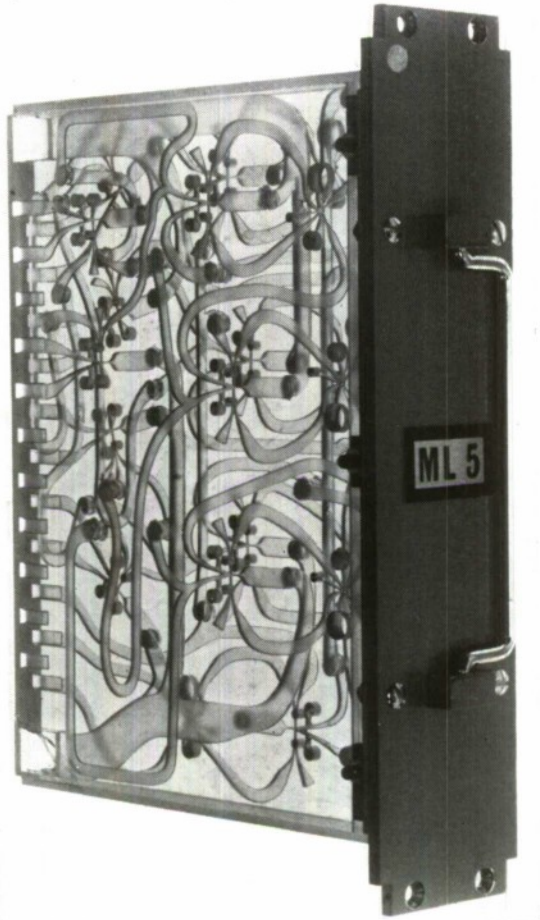

FIG. 9. Fluidic integrated circuit module.

(3) fluidic devices consume power continually while operating and the air consumed by such a large system would have been excessive if not turned off when not needed; conventional pneumatic devices were therefore used to turn on and off the power to the two parts of the fluidic system; they were also used for setting fluidic bi-stables in their correct condition when power was first switched on;

(4) they were also used for certain of the interlocks when complexity would have been increased by performing only small amounts of logic fluidically before returning to higher pressures *via* step-up relays.

The final logic involved 110 fluidic functions such as OR/NOR, bistables, passive AND and analogue amplifiers incorporated in five integrated circuits (IC). Connectors similar to electronic multi-way edge connectors housing 22 signal ports, plus two supply ports, were designed to allow the IC to be withdrawn easily for maintenance or replacement if necessary. Inter-connexions between IC used copper tube but, as conventional couplings were excessively bulky and expensive, heat shrunk plastic sleeves were used. This method is simple, cheap and effective for such low pressure joints and allows easy removal and replacement, if this should prove necessary, without damage to the copper tube.

Numerous test points were provided for easy installation testing and maintenance. These adapted standard tyre valves for use with bayonet fitting probes through which pressure could be measured or test signals injected. Fig. 9 shows a fluidic module before installation in the main console.

Experience during the testing of the pre-production model suggested only one important modification for the production version. An accident resulted in the carbon granules in the filter being distributed throughout the fluidic system. A few gates worked incorrectly due to large granules blocking the ports. These were blown out using an air gun. Though still very dirty with carbon dust the performance was then identical to that of the clean IC. The ICs were easily cleaned using detergent and warm water. Though such an accident should not recur it was decided to put a coarse mesh in the gasket between the connector and IC. This would prevent the large particles from reaching the IC and make their removal even easier.

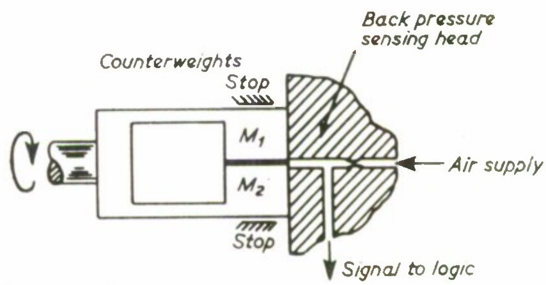

FIG. 10. Speed sensor.

Air Supplies

The source of air pressure for the system is obtained from the 350 lb/in² Diesel air start bottles. For the pneumatics the 350 lb/in² supply is reduced to 70/80 lb/in²g and filtered. The supply to the fluidics is again filtered and further regulated to 2·5 lb/in²g.

Fluidic devices consume power continually while operating, hence the system is designed so that all unwanted air supplies are switched off when not needed.

The maximum air consumption for the system when starting the engine is 7·2 standard ft³/min, this reduces to 3·5 standard ft³/min when on surveillance.

Sensors

With the exception of the liquid level sensor, all parameters were sensed using moving part devices. The various methods used were:

(a) valve position — standard spool valve mechanically positioned;

(b) air supply pressure—diaphragm valve;

(c) oil pressure—diaphragm valve;

(d) level sensor—the fluidic liquid level sensor used a standard back pressure sensing technique to derive a low pressure signal which is then amplified before being passed to the logic; to prevent condensation of vapour from the hot liquid within the amplifiers when the air supply is turned off, special venting is provided in all connections to the dip tube;

(e) speed—the start sequence is ended as a result of 315 rev/min being sensed by the device, the principle of which is shown in Fig. 10—two counter weights are held together by springs on a rotating plate; when the critical rotation speed is reached a gap opens between the counterweights which is sensed by a back pressure sensor, giving a low pressure out at high rotation speeds; for fail safe operation this signal is inverted by a NOR gate so that a 1 is transmitted to the start console at 315 rev/min and above. The speed sensor was designed especially for this contract by English Electric;

(f) temperature—a standard 4 in dial gauge has been adapted so that fluidic signals are given out at certain set points without interfering with the visual presentation; a disc is attached to the pointer spindle with which it rotates; vanes extending from the disc periphery interrupt jet-collector fluidic sensors at the appropriate set points.

Conclusions

Results from the extensive shore based trials have been encouraging, but the real test for systems using fluidic techniques will come during the period of evaluation at sea. It is predicted with confidence that the choice of fluid logic over more conventional methods will be justified by improved reliability in hazardous conditions.

When in the 1970s this system enters service with the Royal Navy it will be the first production system in a naval ship to employ fluidics in such an advanced form.

RESPIRATORY FUNCTION during a SIMULATED SATURATION DIVE TO 1500ft.

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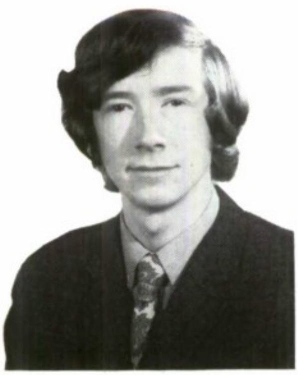


John Florio was educated at Bilborough Grammar School, Nottingham, and Barking Regional College of Technology (now North East London Polytech). He obtained a B.Sc. (External London) Zoology in 1969, joining R.N.P.L. in December 1969, to work on Physiology of Diving and in particular Analysis of Respiratory Gas Exchange at Pressure. In this connection registering for M.Phil. Physiology.

Abstract

A simulated saturation dive was performed in a dry chamber complex. Two subjects were compressed to successive depths of 600 ft., 1000 ft., 1300 ft. and 1500 ft. Time spent at each depth was 24, 24, 22 and 10 hours respectively. The purpose of the dive was to better establish man's physiological state at depths in excess of 1000 ft., a region beyond the limits of man's previous experience.

Respiratory studies were made to assess the effect on normal respiratory function at these depths. Measurements were made of minute ventilation, tidal volume, respiration rate, carbon dioxide production, alveolar carbon dioxide partial pressure and heart rate. These parameters were measured at each depth both when the subjects were at rest and when they were performing a moderate work load. It is concluded from the results that under these conditions, there are no significant respiratory problems and man can exist with reasonable comfort.

Introduction

The primary purpose of the scientific programme to be described was to establish man's underwater capabilities at depths in excess of 1000 ft, a region in which available information was limited and conflicting. The dive was of an exploratory nature beyond the limits of man's previous experience. Prior to this report

research information suggested that man's capacity to operate safely might be restricted to a depth of less than 1200 ft.

In 1968 Brauer[4] and Fructus[10] carried out a series of short deep dives to increasing depths in excess of 1000 ft. reaching a maximum of 1189 ft. This deepest dive was terminated due to gross changes in the electrical activity of the brain (EEG), accompanied by excessive drowsiness of the subjects. These changes, encountered in all dives performed, were evident as compression advanced beyond 900 ft and gradually became worse with increasing depth. Helium tremors began at about 800 ft and became increasingly prominent beyond 1000 ft. These physiological observations termed "the High Pressure Nervous Syndrome" were considered on the basis of animal experiments to be the precursors of convulsions which would occur at slightly greater depths.

The first saturation dive to 1000 ft. took place in December 1968 at Duke University (Salzano *et al.*[24], Overfield *et al.*[22]). The High Pressure Nervous Syndrome experienced in dives beyond this depth did not present a problem. From the available evidence it was concluded that the limits of physiological performance had not been reached.

In 1969, a similar conclusion was drawn from a second simulated saturation dive to 1000 ft at RNPL (Buhlmann *et al.*[5]). In this dive, three subjects took part and underwater excursions were made to 1150 ft. for a total of five hours. At this depth there was still no evidence of the EEG changes, decrease in alertness or motor difficulties which characterised High Pressure Nervous Syndrome and the subjects were able to swim and work underwater without difficulty.

The questions remaining unanswered were whether or not the High Pressure Nervous Syndrome experienced by Brauer represented a true physiological depth barrier, and if so, could it be circumvented by alteration of gas composition or dive profile. Brauer[4] suggested that the answer to the second question was negative. The experience of the dive at RNPL however indicated that with a time to acclimatize at 1000 ft it was possible to advance to 1150 ft without encountering the syndrome, and hence a modified compression profile with prolonged stops at intermediate depths may circumvent the problems. It was primarily to test this hypothesis that the present dive was performed.

Respiratory Function

The purpose of the respiratory measurements was to establish the effects on normal respiratory function of compression to an eventual simulated depth of 1500 ft. In planning the experimental procedure, predictions of respiratory function at this depth and the available information from previous deep saturation dives were considered.

Lanphier[17] and others (Miles[19], Wood[28], Maio and Farhi[18] and Seusing and Drube[26]), have demonstrated the decrease in maximum voluntary ventilation (MVV) with increasing depth, and have related the observed changes to relative gas density. In collating the available experimental data for air and oxygen-helium diving Lanphier[17] extended the predictive curve for oxygen-helium breathing to depths hitherto unattained. The curve suggests that MVV in the region of 95 l/min should be possible at 1000 ft and 80 l/min at 1500 ft. Maximum ventilation sustained at exercise, however, may be considerably less[17]. Measurements at surface suggest a value of 75% of MVV for sustained exercise[27].

Very few experimental measurements have been made of the effects of deep saturation diving on respiratory functions. Dougherty and Schaefer[8] show a decrement of maximum inspiratory and expiratory flow rates on compression to 600 ft, 800 ft and 1000 ft. Partial recovery of these parameters by some 23 to 44% was seen with increasing time at saturation depth. This finding complicates any prediction of respiratory parameters in deep saturation diving. It would appear that due to a time dependent factor these parameters cannot be reliably predicted on the basis of brief exposures to high pressures or by breathing more dense gases at shallower depths. Dougherty and Schaefer[8] also measured a slight reduction of vital capacity which showed a similar tendency to recovery with time of saturation. In contrast Buhlmann *et al.*[5] reported no change in vital capacity at 1000 ft.

Measurements of respiratory function were made during a simulated saturation dive to 600 ft by Bradley *et al.*[3]. Respiratory responses at rest and at a work load of 450 kg-m/min were essentially unaltered from surface values but at a work load of 900 kg-m/min, requiring a minute ventilation of up to 75 l/min one of the two subjects showed a marked increase of oxygen consumption, carbon dioxide production and $\underline{P}_{A,CO_2}$ whilst minute ventilation remained unchanged.

Salzano *et al.*[24] made a detailed study of cardio-respiratory responses at a simulated depth of 1000 ft. Three subjects were investigated at work loads of 275, 582 and 735 kg-m/min. Results showed a greater oxygen consumption than at surface, a larger tidal volume, together with a lower respiratory rate and ventilatory equivalent ($\dot{V}_E/\dot{V}_{O_2}$). These changes were attributed mainly to the effects on pulmonary mechanics of the increased gas density (4·4 times denser than air at 1 atmosphere). Two of the subjects showed abnormally high P_{A,CO_2} levels when performing the heaviest work load requiring a ventilation of up to 55 l/min and an oxygen consumption of just under 2 l/min. Results indicated that men were capable of moderately heavy work at this depth. The effects on pulmonary function were similar to those during air dives to 4·5 atmospheres carried out by Hesser *et al.*[13]. In these studies it was stated that the subjects were subjectively distressed at a work load of 900 kg-m/min, which represented about 60% of the aerobic work capacity. In these experiments P_{A,CO_2} reached a level of over 50 mm Hg.

Miller *et al.*[20, 21] maintain that it is possible for an individual to perform work at a ventilation equivalent to his MVV. Results are presented for four subjects breathing air to a depth of 7·8 atmospheres. Three of the subjects eventually attained a ventilation equivalent to their MVV at depth. There was however some reduction in ventilation from surface values before 'ventilation limitation' at MVV took place. It was predicted also that breathing an oxygen-helium mixture the subjects should be able to maintain heavy work to a depth of approximately 1500 ft. At this depth the gas density would be equivalent to 7 atm of air and the subjects would therefore have a maximum ventilation, equal to their MVV, of about 60 l/min.

As the present dive aimed at an eventual depth 30% greater than any previous saturation dive and in view of the possible problem of the High Pressure Nervous Syndrome a work load substantially below the expected maximal load was used. With regard to predictions of respiratory function and the experimental evidence of previous dives to a lesser depth, it was considered unlikely that maximal effort could be reached at less than a 750 kg-m/min work load which would require an oxygen consumption of about 2 l/min or a ventilation of 60 l/min at the surface. An exercise level of 300 kg-m/min was therefore chosen as a suitable intermediate work load. This was found to represent an oxygen consumption of 1·1 l/min at a ventilation of 25-27 l/min at surface. It was intended that a quantitative analysis of respiration at rest and a moderate work-load would establish a sound basis on which to examine higher work loads in subsequent experiments.

Dive Profile and Procedure The dive took place in the dry chamber complex[9], shown in Fig. 1, of 5·5 ft internal diameter consisting of a 260 cu ft main compartment and a 105 cu ft end lock. Maximum working pressure of the chamber is 69 atmospheres (2,250 ft. of sea water). Chamber temperature was controlled by means of an electrical heating system consisting of tapes wound round the shell of the vessel and covered by an insulating fibreglass jacket. By this method it was possible to maintain the chamber at the temperature which the divers found most comfortable. Each compartment was fitted with a gland through which electrical communications could be made. The glands had a capacity of 14 screened and 48 unscreened leads and carried EEG, ECG, various transducer and communications signals to the instrumentation situated outside the chamber.

In order to remove carbon dioxide, the chamber atmosphere was drawn through soda-lime canisters by means of two impeller fan motors driven by compressed air. Water vapour, ammonia and hydrogen sulphide could be removed in a similar manner, using canisters of silica-gel and carbon granules. In this manner the carbon dioxide level in the chamber was maintained at less than 0·6% of one atmosphere at all times and relative humidity was held in the region of 70 to 90%. The gas mixture specified for the dive was 45% of one atmosphere of oxygen (tolerance ±5%), less than 2% of one atmosphere nitrogen, and the remainder of the gas mixture helium. The correct oxygen level was maintained by means of an oxygen injection system controlled by polarographic sensors. Gas composition was checked by gas chromatograph each hour and a continuous measure of oxygen percentage was available from the polarographic oxygen sensors. At no time during the dive was there any problem in connection with the life support system.

The two divers selected, Bevan and Sharphouse, were on the scientific staff of the Labora-

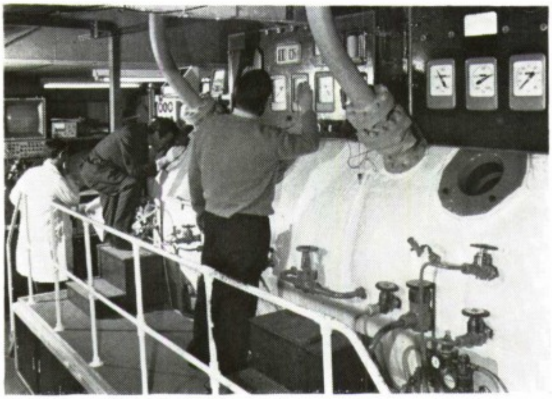


Fig. 1. The chamber complex during the dive.

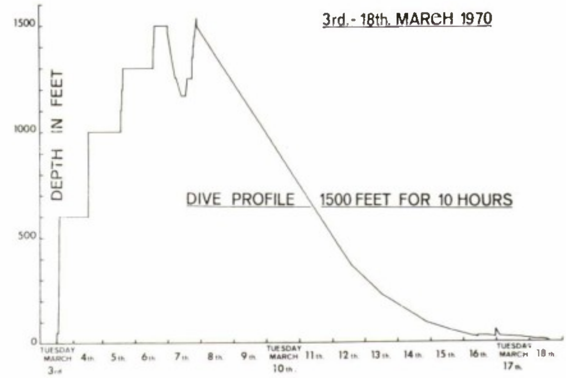


Fig. 2. The dive profile showing the compression stages to 1500 ft and decompression.

tory and had previous simulated and actual diving experience. The dive profile is shown in Fig. 2. The dive took place in stages with major stops of 24 hours at 600 ft and 1000 ft, 22 hours at 1300 ft and 10 hours at 1500 ft. This pattern allowed extensive experimental data to be collected at intermediate and final depths. Compression to 600 ft and hence to 1000 ft was direct at six minutes per 100 ft. From 1000 ft onwards further short stages were introduced with one hour stops at every 100 ft increment. During these stages basic physiological tests were made including EEG, ECG, respiratory rate, alveolar CO_2 and performance tests.

The decompression table was modified at 1180 ft following vestibular problems with Sharphouse and again at 30 ft due to a knee bend with Bevan. A total of $3\frac{1}{2}$ days were spent in excess of 1200 ft the depth at which the physiological barrier had been previously predicted. In the course of the dive, a total of 22 hours of measurements were made of helium tremors, frequency of the electroencephalogram, auditory evoked responses and mechanical and mental performance tests. In addition urine was collected every 24 hours for electrolyte, stress hormone and acidity analysis. Details of these results will be reported elsewhere.[2] A further 20 hours of measurements were made of respiratory function and these measurements will be described in detail in the following paragraphs.

Experimental Methods

A bicycle ergometer was designed in a form suitable for use in the limited space of the pressure chamber. It was constructed of duralumin section and could be easily collapsed and stored under the chamber floor in order to maximise diver living space. When pedalling the ergometer, the subject was positioned on a couch in a semi-reclined posture as shown in Fig. 3. The load wheel was driven through a system of gears giving a 1 to 4·8 ratio. A constant work rate was maintained by applying a constant frictional force to the load wheel and having the subject pedal at a predetermined speed by observing a dial tachometer.

All respiratory measurements were taken with the divers positioned on the bicycle ergometer. Inspiratory gas flows were measured by pneumotachograph and pressure transducer. The pneumotachograph was connected to the inspiratory side of a low resistance mouthpiece. In this manner were avoided problems of temperature variation and condensation associated with measurement of expired gases which would affect calibration of the instrument. The pneumotachograph was calibrated by passing a steady flow of chamber atmosphere through the instrument and measuring the flow-rate by a rotameter external to the chamber. A series of rotameters were used, having calibration charts for the range of gas mixtures used. A calibration of the pneumotachagraph was made during

each experiment. The instrument had a linear response over the range of gas flows measured.

Analog signals of inspiratory gas flow were recorded on magnetic tape and subsequently analysed by computer methods. The analog signals were sampled and digitised by a LINC 8 computer at a rate of 100/sec. Tidal volumes, $\underline{V}_T$, were calculated by integration and minute volume, $\underline{\dot{V}}_I$, and respiration rate, f, measured by means of an internal time clock in the computer.

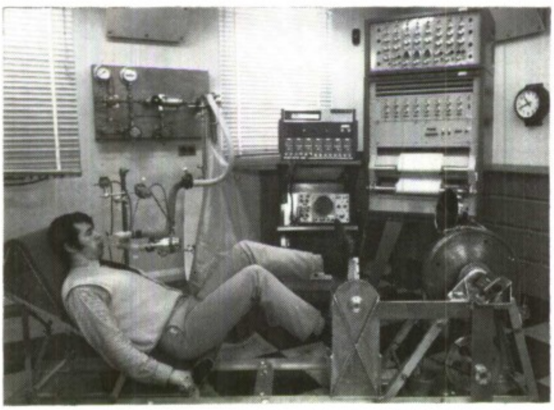


Fig. 3. Bicycle ergometer and recording equipment used in the measurement of ventilation.

End tidal gas samples were taken using an end tidal gas sampling valve and mixed expired gases were collected and sampled. The carbon dioxide content of mixed expired, end tidal and chamber atmosphere gas samples was measured using a Beckman GC-2A gas chromatograph. Oxygen content of these gases was measured by a mass spectrometer. The measurements by mass spectrometer proved unsatisfactory and for this reason no oxygen results are available.

Ventilation was recorded over a period of 20 minutes at rest and a further 11 minutes at an exercise load of 300 kg-m/min. In order to measure the diver in a steady state, the last 10 minutes of the rest period and the last six minutes of the exercise period were analysed. During the experiments, heart rate was also measured. To minimise any effect of training to the bicycle ergometer the divers exercised regularly on the machine before the dive.

Results and Discussion

The main finding of the dive was that no helium barrier existed at 1200 feet. Helium tremors were experienced on compression to each depth and there was some evidence of EEG changes of the type described by Brauer[4] but of a much less severe nature. On the basis of the measurements made it was considered that the symptoms of High Pressure Nervous Syndrome were primarily a compression effect on the system rather than a direct result of pressure[2]. Progress to 1500 ft was therefore possible following acclimatization at intermediate depths, during which the symptoms of High Pressure Nervous Syndrome gradually diminished.

The number of experiments achieved was dependent on the time available for respiratory measurements at each depth. The full experiment as described was performed twice on both divers at 600 ft, 1300 ft and 1500 ft. At 1000 ft both divers were tested three times whilst working at 300 kg-m/min and at rest Bevan was tested three times and Sharphouse twice. The experiment was performed a further four times at surface (on air), including one test 24 hours after completion of decompression. Results of the tests 24 hours after decompression (tests 23 and 24, Tables 1 - 4) showed no significant differences from the other surface tests. Each full experiment with calibrations required approximately one hour.

Ventilations were measured throughout as the volume of gas inspired per minute at BTPS conditions, *i.e.* inspired minute ventilations, $\underline{\dot{V}}_I$. It should be noted that at surface due to the difference of oxygen consumption, $\underline{\dot{V}}_{O_2}$, and carbon dioxide production, $\underline{\dot{V}}_{CO_2}$, values of $\underline{\dot{V}}_I$ may be about 1% greater than the corresponding expired ventilation $\underline{\dot{V}}_E$. At depth, however, due to the lower oxygen percentage, the difference becomes negligible. During the exercise period at surface, the oxygen consumption of the two subjects was measured to be in the range of 1·06 to 1·16 l/min (STPD).

Minute ventilation, $\underline{\dot{V}}_I$, of both divers and the corresponding end-tidal carbon dioxide values, $\underline{P}_{A,CO_2}$, at rest and exercise are shown in Figs. 4 and 5 respectively. When resting, both divers had an increased minute ventilation at all depths. The values of $\underline{\dot{V}}_I$ measured at the various depths, however, did not show any

significant variations. Increase of $\dot{V}_I$ from surface control values was of the order of 2 l/min (approximately 25%) in both divers. Corresponding values of P_{A,CO_2} were lower than normal resting values at surface. There was either no change or a slight increase in resting $\dot{V}_{CO_2}$ values (see Fig. 6).

Increased minute ventilation, $\dot{V}_I$, at rest compared with surface values, and lower values of P_{A,CO_2} suggest that the divers may have been hyperventilating slightly when at rest. Several factors of the environment were altered from the surface control experiments and could contribute to these changes.

Thermal conductivity of the chamber atmosphere was much greater than that of air, and consequently higher ambient temperatures were required to maintain diver comfort. The divers were sensitive to small changes of temperature (± 1°C). Optimum temperature was 29°C at 600 ft increasing to 32°C at 1500 ft. Increased work of breathing due to the greater gas density may have affected ventilation. However, ventilation might be expected to increase gradually at each successive depth due to this factor, and this was not evident. It is also possible that an accurate measurement of end tidal P_{A,CO_2} is impaired by redistribution of airway ventilation due to increased gas density[16].

The partial pressure of oxygen in the gas mixture was elevated to 45% of 1 atmosphere. A raised partial pressure of oxygen tends to increase ventilation at rest resulting in a lowered alveolar carbon dioxide concentration[6, 14]. As this factor of the environment appeared a likely contributor to the changes seen, a further series of tests were made in the laboratory having the subjects breathe 45% oxygen and nitrogen. The results of two such

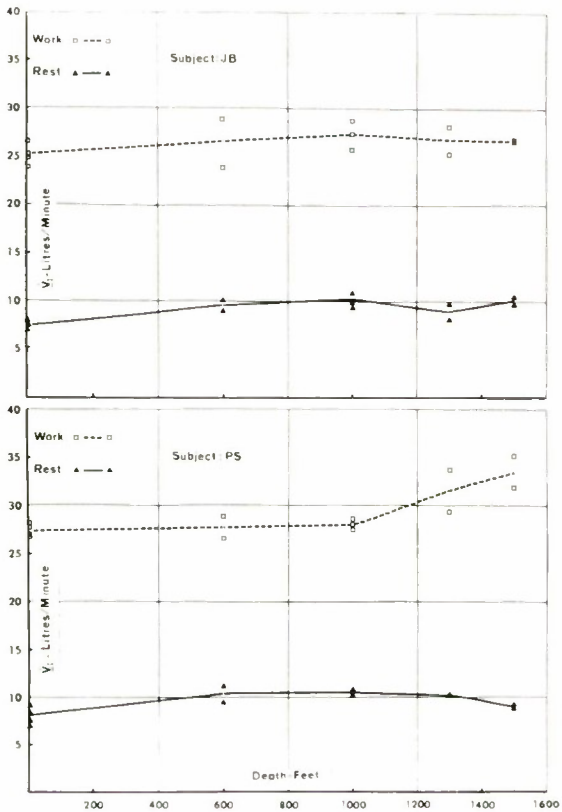


Fig. 4. The relationship of minute ventilation, $\dot{V}_I$, of the two divers, measured at rest and at a work load of 300 kg-m/min, to depth.

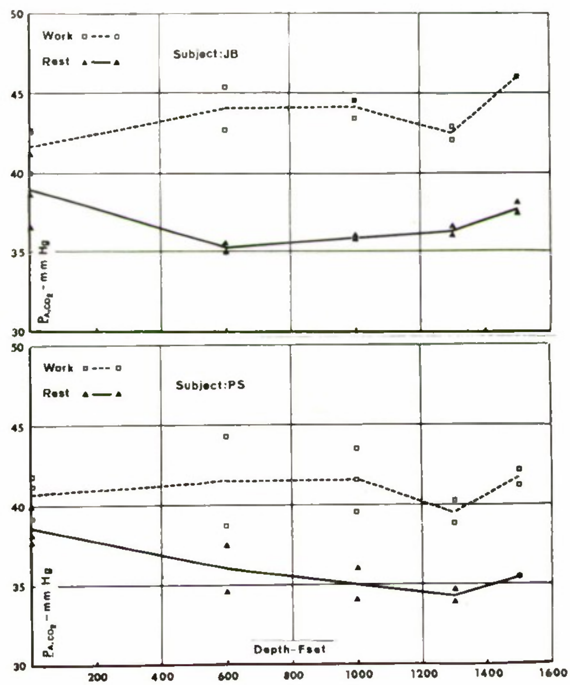


Fig. 5. The relationship of alveolar carbon dioxide partial pressure, P_{A,CO_2}, of the two divers, measured at rest and at a work load of 300 kg-m/min, to depth.

TABLE 1 Respiratory function at rest: Bevan.

TEST NO	DEPTH FT	REL. GAS DENSITY	$\dot{V}_I$ l/min	V_T litres	RESP. RATE	$\dot{V}_{CO_2}$ l/min	P_{A,CO_2} mm Hg	HEART RATE	$\dot{V}_A$ l/min	V_D/V_T
1	0	1.0	7.4	0.51	14.4	0.19				
23			7.6	0.53	14.3	0.23	36.6	73	5.5	0.22
27			6.9	0.46	15.2	0.23	38.7	53	5.2	0.19
28			8.0	0.51	15.4	0.27	41.1	75	5.6	0.23
3	600	3.1	10.1	0.62	16.3		34.9	57		
7			8.8	0.64	13.8	0.24	35.5	59	6.3	0.24
8	1000	4.7	9.9	0.66	14.9	0.26	35.9	55	6.7	0.28
10			10.9	0.68	16.2	0.32	35.7	59	8.3	0.20
12			9.2	0.64	14.5	0.22	36.0	58	5.8	0.32
14	1300	5.9	9.6	0.64	15.1	0.24	36.0	58	6.3	0.30
18			8.1	0.57	14.3	0.19	36.6	59	5.0	0.34
19	1500	6.7	9.6	0.72	13.4	0.26	38.1	61	6.5	0.28
21			10.5	0.79	13.2	0.27	37.6	57	7.0	0.29

TABLE 2.
Respiratory function at 300 kg-m/min work load: Bevan.

TEST NO	DEPTH FT	REL. GAS DENSITY	$\dot{V}_I$ l/min	V_T litres	RESP. RATE	$\dot{V}_{CO_2}$ l/min	P_{A,CO_2} mm Hg	HEART RATE	$\dot{V}_A$ l/min	V_D/V_T
1	0	1.0	23.9	1.30	18.4	0.96				
23			26.8	1.37	19.6	0.96	40.0	109	21.0	0.19
27			24.9	1.28	19.5	1.03	42.7	98	21.0	0.14
28			25.3	1.28	19.8	1.03	42.6	108	20.9	0.15
3	600	3.1	28.7	1.48	19.4		42.7	93		
5			23.8	1.34	17.7	0.95	45.3	88	19.4	0.16
8	1000	4.7	27.2	1.61	16.9	1.06	44.5	93	21.7	0.18
10			25.9	1.53	17.1	1.02	44.5	82	21.1	0.17
12			28.7	1.64	17.5	0.97	43.5	90	20.8	0.26
14	1300	5.9	28.1	1.59	17.7	0.94	42.9	88	20.7	0.24
16			25.6	1.50	17.1		42.2	82		
19	1500	6.7	26.6	1.75	15.2	1.02	46.1	94	20.9	0.20
21			26.9	1.97	13.7	1.00	46.2	85	20.9	0.21

TABLE 3. Respiratory function at rest: Sharphouse.

TEST NO	DEPTH FT	REL. GAS DENSITY	$\dot{V}_I$ l/min	V_T litres	RESP. RATE	$\dot{V}_{CO_2}$ l/min	P_{A,CO_2} mm Hg	HEART RATE	$\dot{V}_A$ l/min	V_D/V_T
2	0	1.0	9.2	0.53	17.5	0.26				
24			7.4	0.56	13.3	0.24	37.6	58	5.4	0.21
25			7.5	0.49	15.1	0.22	39.9	56	5.0	0.30
26			8.3	0.49	17.1	0.25	38.2	72	5.7	0.25
4	600	3.1	11.1	0.78	14.3	0.31	37.5	54	7.7	0.27
6			9.6	0.71	13.6	0.26	34.6	62	7.0	0.23
9	1000	4.7	10.2	0.67	15.3	0.27	36.1	50	7.0	0.27
11			10.9	0.69	16.1	0.29	34.0	52	8.3	0.20
15	1300	5.9	10.1	0.66	15.5	0.24	34.6	53	6.7	0.30
17			10.2	0.72	14.4	0.25	33.8	55	7.5	0.24
20	1500	6.7	9.3	0.60	15.4	0.24	35.5	57	6.7	0.22
22			8.8	0.73	12.1	0.20	35.5	49	5.7	0.31

TABLE 4.
Respiratory function at 300 kg-m/min work load: Sharphouse.

TEST NO	DEPTH FT	REL. GAS DENSITY	$\dot{V}_I$ l/min	V_T litres	RESP. RATE	$\dot{V}_{CO_2}$ l/min	P_{A,CO_2} mm Hg	HEART RATE	$\dot{V}_A$ l/min	V_D/V_T
2	0	1.0	27.1	1.31	20.7	1.02				
24			28.3	1.47	19.4	1.05	39.2	104	23.2	0.17
25			26.8	1.28	20.9	1.02	41.8	109	21.0	0.19
26			27.8	1.16	24.1	1.01	41.1	108	21.3	0.21
4	600	3.1	26.7	1.75	15.7	1.00	44.2	100	21.7	0.19
6			28.9	1.35	21.8	0.99	38.7	79	23.3	0.19
9	1000	4.7	27.7	1.48	18.9	0.99	43.3	71	21.0	0.23
11			28.4	1.58	18.2	0.99	41.5	77	23.0	0.18
13			28.9	1.90	15.6		39.5	80		
15	1300	5.9	29.3	1.62	18.3	0.97	40.3	72	23.2	0.20
17			33.8	1.58	21.4	1.00	38.8	85	24.6	0.25
20	1500	6.7	31.9	1.87	17.3	1.11	42.1	90	26.4	0.17
22			35.1	1.93	19.2	1.19	41.2	78	28.4	0.17

tests on each subject showed that $\dot{V}_I$ remained within the range of normal surface controls. When the subjects breathed air and then 45% oxygen and nitrogen for consecutive periods of 20 minutes, the end tidal P_{A,CO_2} measured while breathing 45% oxygen was consistently 1 mm Hg lower than the value obtained breathing air. This reduction of P_{A,CO_2} was not as great as that measured during the dive.

Although appearing relaxed and confident at all times, there is some evidence[2] that during the experiments at pressure the subjects were under a degree of stress, probably due to the significance of the dive and the rigorous experimental programme. It is considered that the changes in respiratory function at rest are of minor imporance and that all four factors mentioned above would probably contribute to their effect.

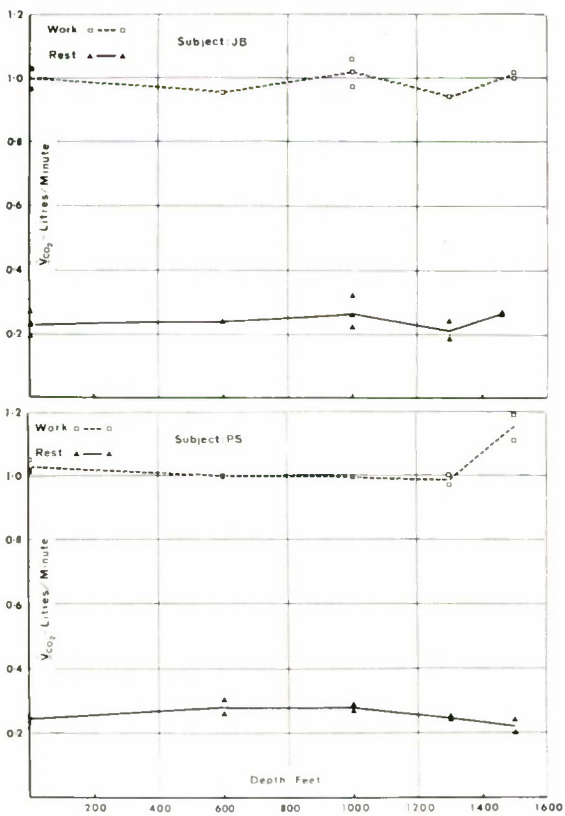


Fig. 6. The relationship of carbon dioxide production, $\dot{V}_{CO_2}$, of the two divers, measured at rest and at a work load of 300 kg-m/min, to depth.

Measurements by Schaefer[25] of resting respiration during a saturation dive to 7 atmospheres when breathing an oxygen-helium-nitrogen mixture of density 1·5 times that of air at 1 atm show a 100% increase in ventilation and an average resting P_{A,CO_2} of 45·1 mm Hg. Changes were considered to be due to high gas density, chamber environment (1·17% of 1 atm CO_2) and diver acclimatisation. The relatively small changes measured in ventilation and P_{A,CO_2} at rest when saturated at 46·5 atmospheres and breathing a gas of density 6·7 times that of air at 1 atmosphere indicate that the effects of gas density or hydrostatic pressure on resting respiration are negligible. Down to 1500 ft, therefore, alterations seen in resting respiration are most likely a function of chamber environment.

When performing the moderate exercise load, ventilations were again increased, on average, by about 1 to 2 l/min from surface values (Fig. 4). In both exercise periods at 1500 ft and in one at 1300 ft Sharphouse had a more marked increase in ventilation of 5 to 8 l/min above the surface average of 27 l/min. At 1300 ft $\dot{V}_{CO_2}$ was unchanged (see Fig. 6) and the increased ventilation of 33·8 l/min was accompanied by a correspondingly lower P_{A,CO_2} of 38·8 mm Hg. At 1500 ft however P_{A,CO_2} remained normal and $\dot{V}_{CO_2}$ increased in relation to the greater $\dot{V}_I$ suggesting either a higher level of work output by Sharphouse at this depth or an alteration of ventilation equivalent ($\dot{V}_E/\dot{V}_{O_2}$) and respiratory exchange ratio, R, ($\dot{V}_{CO_2}/\dot{V}_{O_2}$).

There was no increase of $\dot{V}_I$ in Bevan beyond 1000 ft and $\dot{V}_{CO_2}$ did not vary from surface values. In both exercise periods at 1500 ft there was a significant increase of P_{A,CO_2} from 42·5 mm Hg at surface to 46·3 mm Hg. In both subjects it can be seen from Tables 2 and 4 that variations of $\dot{V}_I$ at a given depth were matched by corresponding variations of P_{A,CO_2}, a higher ventilation resulting in a lower P_{A,CO_2}.

When performing moderate exercise, the increase of 1 to 2 l/min in ventilation does not fully reflect the increased work of breathing a denser gas. For a gas density similar to that

breathed by the divers at 1000 ft, Glauser *et al.*[11] measured an increment in oxygen consumption of 5 ml O_2/litre $\dot{V}_E$ when ventilating at 36·4 l/min. Using this value and assuming a $\dot{V}_E/\dot{V}_{O_2}$ ratio of 24 would require an increase in ventilation of about 3·3 l/min at 1000 ft and above this value at greater depths. This suggests that with the exception of Sharphouse at 1500 ft there was a reduction of both $\dot{V}_E/\dot{V}_{O_2}$ ratio and $\dot{V}_{CO_2}/\dot{V}_{O_2}$ ratio at depth.

It is of interest to note that the different responses of subjects to exercise at 1500 ft were also evident in the results of Salzano *et al.*[24] at 1000 ft. Salzano estimated that the oxygen cost of respiration was 8 to 10 ml O_2/litre $\dot{V}_E$ compared with 2 ml O_2/litre $\dot{V}_E$ at surface. When performing moderate exercise (275 kg-m/min) two subjects showed a reduced $\dot{V}_E/\dot{V}_{O_2}$ ratio and R value, ventilations and carbon dioxide production remaining unaltered from surface values. A third subject showed an increase of these parameters in relation to the increased oxygen consumption and a $\dot{V}_E/\dot{V}_{O_2}$ ratio similar to that at surface was maintained.

It has been suggested[15, 25] that these differing respiratory responses relate to a subject's diving experience. Due to the increased work of breathing at depth, an experienced diver will tolerate a higher P_{A,CO_2} level rather than increase his ventilation to maintain a normal $\dot{V}_E/\dot{V}_{O_2}$ ratio.

In Fig. 7 is shown the relationship of carbon dioxide elimination, $\dot{V}_{CO_2}$, to ventilation $\dot{V}_I$. As $\dot{V}_{CO_2}$ values remained relatively unchanged at depth the increase of minute ventilation resulted in a higher $\dot{V}_I/\dot{V}_{CO_2}$ ratio than at surface. At rest, the lower values of P_{A,CO_2} indicate that the change in $\dot{V}_I/\dot{V}_{CO_2}$ ratio may be due to slight hyperventilation. When performing work, however, the P_{A,CO_2} values of both subjects were unchanged or slightly higher than at surface. This would indicate a slightly less efficient CO_2 elimination per litre ventilation, $\dot{V}_I$, at depth. Most of the change in $\dot{V}_I/\dot{V}_{CO_2}$ ratio can be attributed to the presence of CO_2 in the chamber atmosphere during the dive. Inspired CO_2 increased from 0·2% of 1 atmosphere at 600 ft to 0·5% of 1 atmosphere at 1500 ft. From the equation[17]

$$K \times \dot{V}_{CO_2} = \dot{V}_A(P_{A,CO_2} - P_{I,CO_2}) \quad \ldots (1)$$

it can be seen that if P_{I,CO_2} increases, then to maintain a constant $\dot{V}_{CO_2}$, either $\dot{V}_A$ or P_{A,CO_2} must be increased also.

Values of alveolar ventilation, $\dot{V}_A$, and physiological deadspace, V_D, were calculated using the equations[6, 7, 17]

$$V_D = \frac{(P_{A,CO_2} - P_{E,CO_2})\,V_T}{(P_{A,CO_2} - P_{I,CO_2})} - V_{D\ Inst} \quad \ldots (2)$$

$$\dot{V}_A = f \times V_A \quad \ldots (3) \text{ and}$$

$$V_A = V_T - (V_D + V_{D\ Inst}) \quad \ldots (4)$$

Results are shown in Tables 1 - 4. Deadspace of the mouthpiece, $V_{D\ Inst}$, was of the order of 30 ml. Sharphouse showed an increase in $\dot{V}_A$

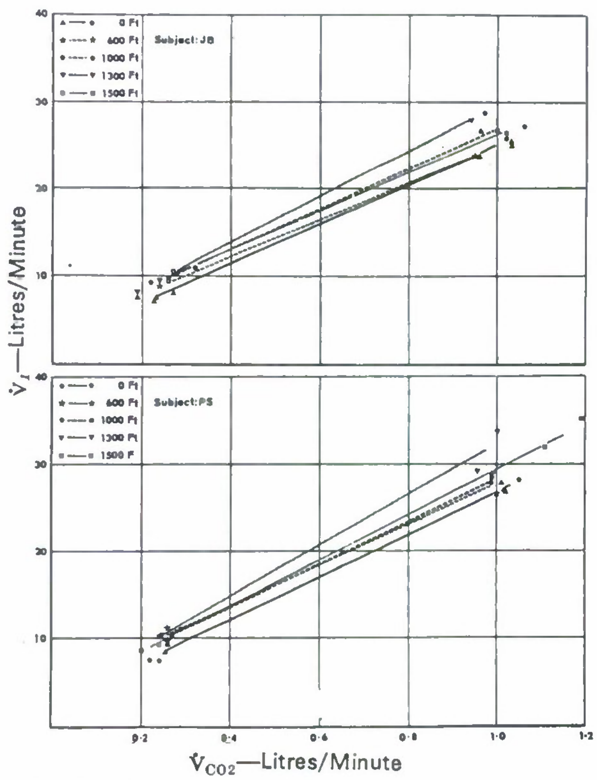


Fig. 7. The relationship of ventilation, $\dot{V}_I$, to carbon dioxide production, $\dot{V}_{CO_2}$, at surface and under pressure.

at depth in proportion to increased $\dot{V}_I$, and the physiological dead space ratio $\underline{V}_D/\underline{V}_T$ remained relatively constant. Results indicated Bevan to have an increase in physiological dead space ratio at depth. Under normal conditions, percentage dead space reduces as tidal volume is increased[6]. As tidal volumes were considerably increased at depths, (Fig. 8), a lower $\underline{V}_D/\underline{V}_T$ ratio might have been expected. The results suggest therefore that in both divers, the relationship of $\underline{V}_D$ to $\underline{V}_T$ may have been altered during the dive. As with inspired CO_2, an increase in $\underline{V}_D/\underline{V}_T$ ratio would cause a rise in either $\underline{P}_{A,CO_2}$ or ventilation if $\underline{\dot{V}}_{CO_2}$ is to be maintained constant.

In contrast to increased ventilation at depth, resting respiratory rates, although mainly within the limits of surface control values, were slightly lower on average, the effective decrease being more marked at 1500 ft (Tables 1 and 3).

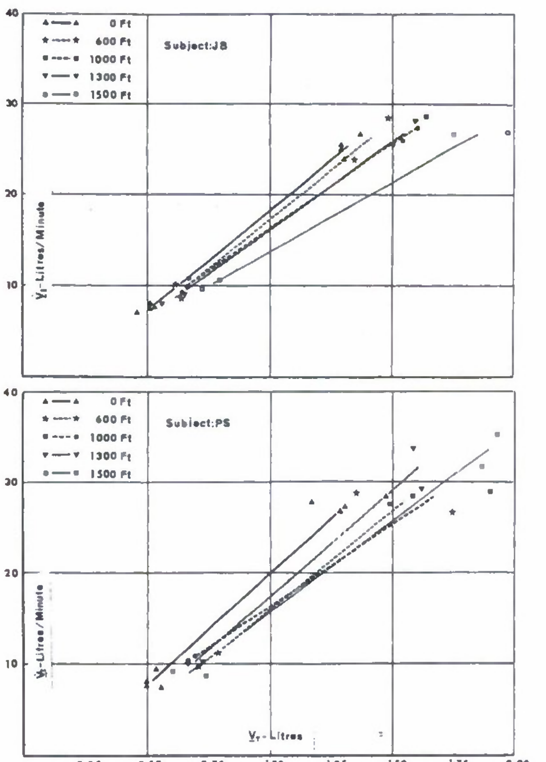


Fig. 8. The relationship of ventilation, $\underline{\dot{V}}_I$, to tidal volume, $\underline{V}_T$, at surface and under pressure.

At rest, mean tidal volumes, $\underline{V}_T$, were increased by 20 - 50% at depth.

Respiratory rates during exercise showed a gradual decrease with increasing depth in both Sharphouse and Bevan from an average of 22 and 19 at surface to 18 and 15 respectively at 1500 ft. Correspondingly there was a considerable increase in mean tidal volume, $\underline{V}_T$, at depth over surface values. At 1000 ft, $\underline{V}_T$ values were over 20% greater in both divers, although $\underline{\dot{V}}_I$ had increased by only 4 to 10%. At 1500 ft Bevan had a 44% increase in $\underline{V}_T$ with no further increase of $\underline{\dot{V}}_I$, and Sharphouse a 52% increase in $\underline{V}_T$ at a minute ventilation 23% greater than surface values.

The considerable alteration to the relationship of minute ventilation to respiratory rate and tidal volume at depth was to be expected, and is in agreement with the findings of previous work[13, 23, 24]. These changes relate to the mechanics of breathing a denser medium[13] and are most probably brought about in order to reduce the work of breathing[23]. It is also possible that at high ventilations, a lower respiratory rate may delay the onset of dynamic compression of the airways by reducing flow-rates at a given lung volume.

The relationship of ventilation to tidal volume is shown in Fig. 8. The mean slope of the relationship at each depth is shown, and the corresponding gas density given in Table 1. The change in slope of the relationship suggests a possible correlation with increasing gas density in the case of Bevan. Sharphouse, who was a more irregular breather, shows a similar change in $\underline{\dot{V}}_I/\underline{\dot{V}}_T$ ratio at depth but the scatter of data is too great to suggest a relationship beyond 600 ft.

Resting heart-rates remained relatively constant at all stages of the dive, and although mainly within the limits of surface values, were lower on average. A significant reduction of heart-rate was evident in both divers when performing exercise at depth (Fig. 9). With the exception of test four on Sharphouse, there was no apparent increase in the bradycardia effect beyond 600 ft. Previous reports have shown bradycardia to be caused by higher oxygen partial pressure and increased hydrostatic pressure or gas density[12, 13, [illegible]]. As previous experiments have been confined to one depth

or gas density, the form of the relationship of bradycardia to gas density has not been established. From the results of this experiment it would appear that the relationship of bradycardia to depth or gas density is of a non linear nature. When breathing an oxygen-helium mixture the further bradycardia effect beyond 600 ft is negligible at rest and moderate exercise. It is also possible that there was an increasing acclimatisation effect, but during the 24 hours or less at each depth there was no evidence to suggest that this was the case.

In the opinion of the subjects performing the work load, it was well within their capabilities at all depths. At 1500 ft the subjects were conscious of an increased resistance to breathing and a considerable increase in body temperature during the exercise period. The limited tolerance to temperature change when resting meant that a single temperature could not be obtained at which the divers were comfortable both at rest and when performing moderate work. It was considered that a higher work load could be achieved without undue stress, but in view of the increased breathing resistance and overheating problems, very heavy work loads could not have been maintained.

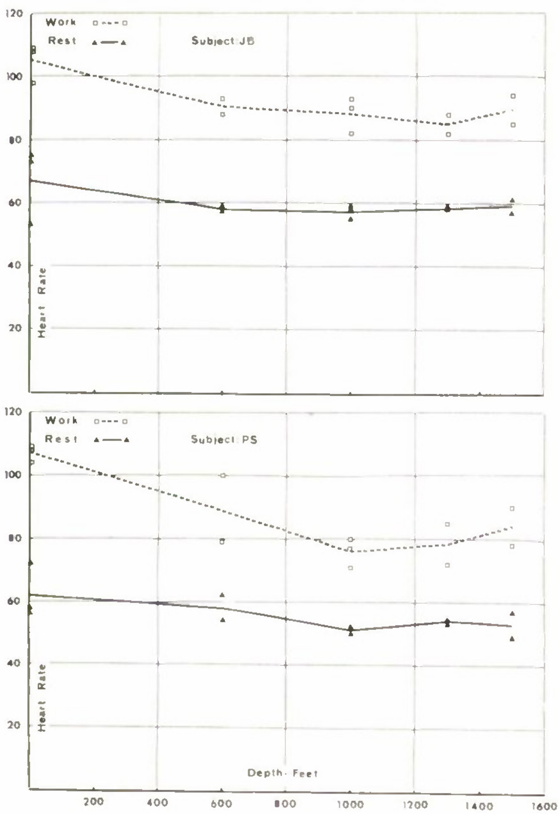


Fig. 9. The relationship of heart rate of the two divers, measured at rest and at a work load of 300 kg-m/min, to depth.

Even two hours after arrival at 1500 ft, Bevan displayed considerable tremor and muscle jerk whilst assembling the bicycle ergometer. These symptoms did not affect his ability to perform the work load in any way, but it was obvious that the performance of any task requiring both moderate effort and a degree of precise movement would be affected in both speed of operation and quality. These effects had subsided at the time of the second test period, six hours after compression. Sharphouse displayed no visible evidence of impairment in function although his measured tremor was increased from surface control values[2].

In chamber dives to a simulated depth of 300 - 800 ft breathing oxygen-helium mixture, Bennett[1] postulated that the tremor, nausea and performance impairment experienced might be the result of hypercapnia due to the raised partial pressure of oxygen in a helium environment. He further suggested that limitation of oxygen partial pressure to 0·5 atm beyond 400 ft may avoid these symptoms. At 1000 ft, (P_{O_2} <0·5 atm) Overfield[22] reported no hypercapnia effect or impairment of function. In the present experiment as stated, Bevan displayed considerable tremor and muscle jerk during the first few hours at 1500 ft. There was no evidence however of hypercapnia at this time when resting or exercising (test 19). This result indicates that the symptoms of 'Deep Water Blackout'[1] or High Pressure Nervous Syndrome[4] although possibly made worse by raised P_{O_2} and carbon dioxide retention, basically result from a different mechanism. From the evidence of this dive[2] and that of Buhlmann *et al.*[5] it is considered that these symptoms are primarily a compression effect.

Conclusions The physiological changes observed during the dive can be summarised as follows:

(1) Minute ventilation showed a slight increase at depth during both rest and moderate exercise. At 1500 ft Sharphouse showed a marked increase in minute ventilation.

(2) Carbon dioxide elimination remained relatively constant at both rest and exercise except in Sharphouse, where at 1500 ft a significant rise in $\dot{V}_I$ was accompanied by a corresponding increase in $\dot{V}_{CO_2}$.

(3) Resting values of P_{A,CO_2} were on average slightly lower at depth than at surface. During moderate exercise P_{A,CO_2} showed a small rise at depth in Bevan but remained unaltered in Sharphouse.

(4) The relationship of respiratory rate and tidal volume to minute ventilation was altered considerably. Respiratory rates were reduced and tidal volumes increased.

(5) There was some evidence of bradycardia at rest and more significantly when exercising. The extent of bradycardia did not alter significantly with increasing depth from 600 to 1500 ft.

(6) When resting the divers were sensitive to changes in chamber temperature of ±1°C. At a comfortable resting temperature, the moderate work-load performed caused the divers to overheat.

In general it can be concluded from the experiment that man can exist with reasonable comfort in an oxygen-helium environment down to a depth of 1500 ft. When resting or performing moderate work under the conditions described there are minor changes in respiratory function but no significant respiratory problems.

Acknowledgements The authors wish to thank Mr. W. S. Butt and Mr. I. C. Mayo for their valuable assistance with the experimental work described. Divers J. Bevan and P. Sharphouse also operated as technicians in the chamber and their assistance is greatly appreciated.

The dive programme was co-ordinated by Dr. P. B. Bennett. Medical safety and decompression was controlled by Dr. E. E. P. Barnard and chamber control was the responsibility of Mr. J. Eaton. The dive was authorised by Dr. H. V. Hempleman, Superintendent, RNPL.

References

(1) Bennett, P. B. (1967). Performance impairment in deep diving due to nitrogen, helium, neon and oxygen; Proc. 3rd Symp. Underwater Physiology (Ed. Lambertsen, C. J. pp. 327, 340), Williams and Wilkins, Baltimore, Md.

(2) Bennett, P. B. (1971). In " Report on 1500 ft. simulated saturation dive ". R.N. Physiological Laboratory: to be published.

(3) Bradley, M. E., Vorosmarti, J., Linaweaver, P. G. and Mazzone, W. F. (1968). U.S. Navy Deep Submergence Systems Project. Research Report 1 - 68.

(4) Brauer, R. W. (1968). Seeking man's depth level: Ocean Industry, **3**, 12, 28 - 33.

(5) Buhlmann, A. A., Matthys, H., Overrath, G., Bennett, P. B., Elliott, D. H. and Gray, S. P. (1970). Saturation exposures at 31 Ata in an oxygen helium atmosphere with excursions to 36 Ata. Aerospace Medicine, **41**, 4, 394 - 402.

(6) Cotes, J. E. (1968). Lung Function: Assessment and Application in Medicine. Blackwell Scientific Publications, Oxford and Edinburgh.

(7) Dejours, P. (1966). Respiration: Oxford University Press, New York.

(8) Dougherty, J. H. and Schaefer, K. E. (1969). The effect on pulmonary functions of rapid compression in saturation-excursion dives to 1000 feet. Report No. 573, U.S. Navy Sub. Med. Center.

(9) Eaton, J. (1971). In " Report on 1500 ft. simulated saturation dive". R.N. Physiological Laboratory to be published.

(10) Fructus, P. (1969). Deep diving. In: Oceanology International 69, Brighton.

(11) Glauser, S. C., Glauser, E. M. and Rusy, B. F. (1967). Gas density and the work of breathing, J. Respiration Physiology, **2**, 344 - 350.

(12) Hamilton, R. W. (1967). Physiological responses at rest and in exercise during saturation at 20 atmospheres of $He\text{-}O_2$. Proc. 3rd Symp. Underwater Physiology. Ed. Lambertsen, C. J. pp. 361 - 374, Williams and Wilkins; Baltimore, Md.

(13) Hesser, C. M., Fagraeus, L. and Linnarsson, D. (1968). Cardio-respiratory responses to exercise in hyperbaric environment; Lab. of Aviation and Naval Medicine, Stockholm.

(14) Lambertsen, C. J. (1963). Physiological effects of oxygen. Proc. 2nd Symp. Underwater Physiology, Ed. Lambertsen, C. J. and Greenbaum, L. J. pp. 171 - 187, Washington; Natl. Acad. Sci. - Natl. Res. Council.

(15) Lanphier, E. H. (1963). Influence of increased ambient pressure upon alveolar ventilation. Proc. 2nd Symp. Underwater Physiology. Ed. Lambertsen, C. J. and Greenbaum, L. J. pp. 124 - 131. Washington: Natl. Acad. Sci - Natl. Res. Council.

(16) Lanphier, E. H. (1967). Interactions of factors limiting performance at high pressures. Proc. 3rd Symp. Underwater Physiology. Ed. Lambertsen, C. J. pp. 375 - 385. Williams and Wilkins, Baltimore, Md.

[17] Lanphier, E. H. (1969). Pulmonary Function. In "Physiology and Medicine of Diving and Compressed Air Work". Ed. Bennett, P. B. and Elliott, D. H. pp. 58 - 112 Baillière, Tindall and Cassell; London.

[18] Maio, D. A. and Farhi, L. E. (1967). Effect of gas density on mechanics of breathing. J. Appl. Physiol., **23,** 687 - 693.

[19] Miles, S. (1969). Underwater Medicine Ed. III. Staples Press; London.

[20] Miller, J. N., Wangensteen, O. D. and Lanphier, E. H. Ventilatory limitations of exertion at depth. Proc. 4th Symp. Underwater Physiology, Academic Press, New York (in press).

[21] Miller, J. N., Wangensteen, O. D. and Lanphier, E. H. (1970). Respiratory limitations to work at depth. Les Troisiemes Journees d'Hyperbarie et de Physiologie Subaquatique. Marseilles, to be published.

[22] Overfield, E. M., Saltzman, H. A., Kylstra, J. A. and Salzano, J. V. (1969). Respiratory gas exchange in normal men breathing 0·9% oxygen in helium at 31·3 Ata. J. Appl. Physiol., **27,** 4. 471 - 475.

[23] Salzano, J. V., Bell, W. H., Weglicki, W. B. and Saltzman, H. A. (1967). Metabolic, respiratory and haemodynamic responses to exercise at increased oxygen pressure. Proc. 3rd Symp. Underwater Physiology. Ed. Lambertsen C. J. pp. 351 - 360. Williams and Wilkins, Baltimore, Md.

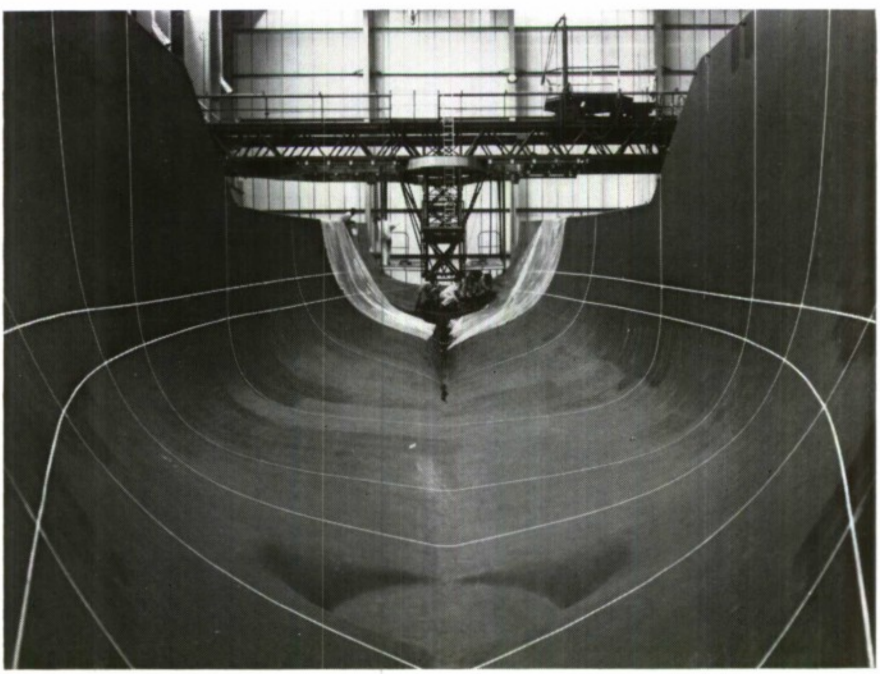
[24] Salzano, J., Rausch, D. C. and Saltzman, H. A. (1970). Cardiorespiratory responses to exercise at a simulated seawater depth of 1000 feet. J. Appl. Physiol., **28,** 34 - 41.

[25] Schaefer, K. E., Bond, G. F., Mazzone, W. M., Carey, C. R. and Dougherty J. H. (1968). Carbon dioxide retention and metabolic changes during prolonged exposure to high pressure environment. J. Aerospace Medicine, 1206 - 1215.

[26] Seusing, J. and Drube, H. C. (1960). Die Bedeutung der Hyperkapnie fur das Auftreten des Triefenrausches. Klin. Wschr. **38,** 1088 - 1090.

[27] Shephard, R. J. (1967). The maximum sustained voluntary ventilation in exercise. Clin. Sci., **32,** 167 - 176.

[28] Wood, W. B. (1963). Ventilatory dynamics under hyperbaric states. Proc. 2nd Symp. Underwater Physiology. Ed. Lambertsen, C. J. and Greenbaum, L. J. pp. 108 - 123. Washington; Natl. Acad. Sci. - Natl. Res. Council.



A view of the hull mould of the R.N. Glass Reinforced Plastic minehunter H.M.S. *Wilton* now under construction at the Vosper Thornycroft shipyard at Woolston. She is to be 153ft. long and will be the largest GRP vessel in the world.

THE LEAD-SILVER OXIDE CELL

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Abstract

Tests have been carried out on several hundred lead-silver oxide cells. Originally developed by the U.S. Naval Ordnance Laboratory, the cells were manufactured by the Mallory Battery Company in the United Kingdom.

The storage life of the uncharged cell exceeds nine years in temperate conditions. At least 70 per cent output is available after 52 weeks temperate or 26 weeks desert storage in the charged state.

The particular size of cell tested has an output of about 1500 mAh. The open circuit voltage is about 0·92 and the discharge voltage is in the range 0·6 to 0·8 V depending on discharge rate and temperature. Essentially suited to low current drains, full output is obtained over the temperature range −20 to +20°C at the 100 hr. rate.

The cell requires about 60 hr. to be fully charged at a constant potential of 1·23 V although about 80 per cent charge is accepted in 15 to 20 hr. Higher charging potentials result in the formation of a higher oxide of silver and are therefore to be avoided.

Intended for single discharge applications, to be charged immediately before use, the cell has been found to be capable of a number of charge-discharge cycles, although output in this type of use is limited to about 1000 mAh.

Introduction

The lead-silver oxide cell was developed by the United States Naval Ordnance Laboratory, White Oak, Silver Springs, Maryland(1) and produced in the United States by the Mallory Battery Company. A feature of particular interest was the long storage life claimed for the cell and to obtain information on this point, and on the general characteristics of the cell, the Mallory Battery Company in the United Kingdom manufactured a number of cells based on the system for the Admiralty Engineering Laboratory in 1961 against an Admiralty contract. The purpose of this article is to describe the main features of the cell observed in tests carried out during the past nine years.

Cell Description

General constructional details and approximate dimensions of the cell manufactured for the tests are shown in Figs. 1 and 2. A mixture of powdered lead oxide and graphite is pressed into the lead plated steel top shell and silver powder into the nickel plated steel bottom shell, the two halves are separated by a barrier layer next to the silver powder and an absorbent mat against the lead oxide-graphite mixture. The 40 per cent potassium hydroxide electrolyte is absorbed in the mat. The cell is sealed with an elastomer grommet which also insulates the top and bottom shells from each other.

The cell as manufactured is in the uncharged state and it is normally stored in this state

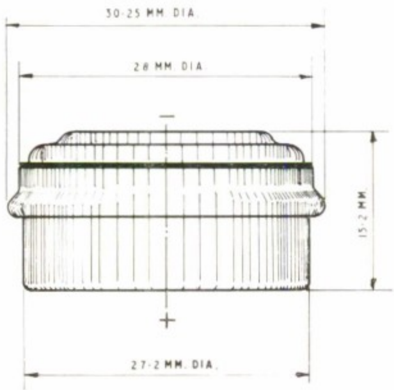

FIG. 1. Lead-Silver Oxide Cells. Dimensions.

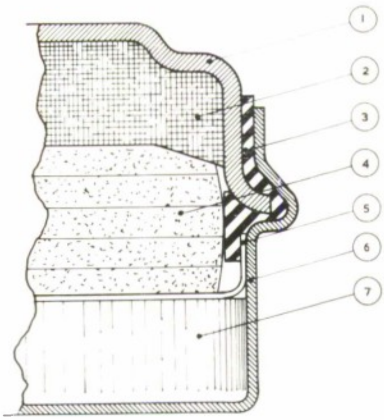

FIG. 2. Lead-Silver Oxide Cells. Constructional Details.

1. Lead plated steel, 2. Grey oxide of lead and graphite, 3. Insulating and sealing grommet, 4. Electrolyte Absorbent, 5. Barrier layer, 6. Nickel plated steel, 7. Silver powder.

until required for use. On charge the lead oxide is reduced to lead and the silver powder converted to silver oxide. Because of the possible harmful effect of silver (II) oxide on the barrier layer, and also because its presence results in an additional, higher voltage, step in the discharge curve and consequently to a worsening of voltage regulation, it has been recommended that the voltage on charge be limited to a value below that at which the higher oxide is formed. A cell fully charged in accordance with this limitation has an open circuit voltage of about 0·92 V and the discharge reaction may be represented as

$$Ag_2O + Pb \rightarrow PbO + 2Ag. \; E = 0{\cdot}925^{(2)}$$

Charging Procedure

The available information recommended constant potential charging at 1·12 ± 0·03 V per cell for about 70 hr, with 1·19 V as the maximum charging potential; 72 hr charge at 1·12 V constant potential was therefore adopted as the standard charging procedure and used as the basis for comparison of other procedures.

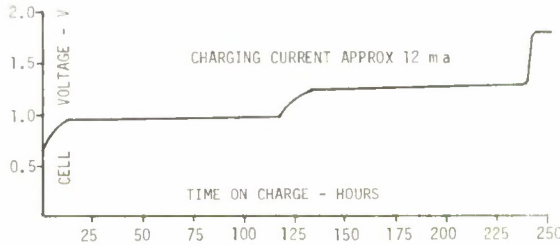

FIG. 3. Charging curve for Lead-Silver Oxide Cell at approximately 12 ma constant current.

A charge at a constant current of 12 mA indicated (Fig. 3) that the higher oxide of silver was probably formed at a potential of about 1·3 V. This was confirmed when a two step discharge curve was obtained after a 36 hr charge at a constant potential of 1·4 V (Fig. 4). The voltage was kept below 1·3 V therefore in all other charging tests. Consequent upon this limitation only two other charging procedures were used: 1·19 V constant potential for 72 hr; and 1·23 V constant potential for 72 hr.

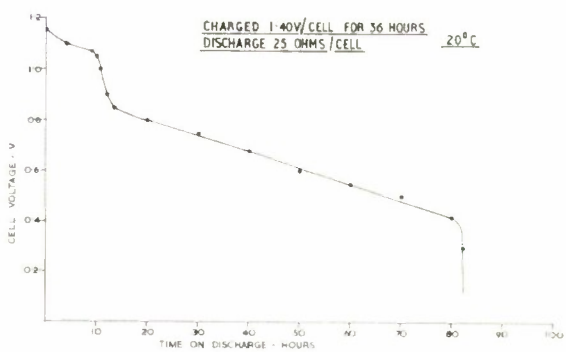

FIG. 4. Voltage-Time curve for Lead-Silver Oxide Cell charged for 36 hr at 1·40 v/cell on discharge load of 25 ohms/cell at 20°C.

The current-time curves, current limited to 1 A maximum, for charging at the three potentials, indicated (Fig. 5) that although the cells continued to take charge for more than 60 hr, the greater part of the charging took place during the first 30 hr of charge and that the total charge during the next 30 hr amounted to no more than about 200 mAh. Some charges were carried out therefore at each of the three constant potentials for times of 15, 20, 25 and 30 hr only.

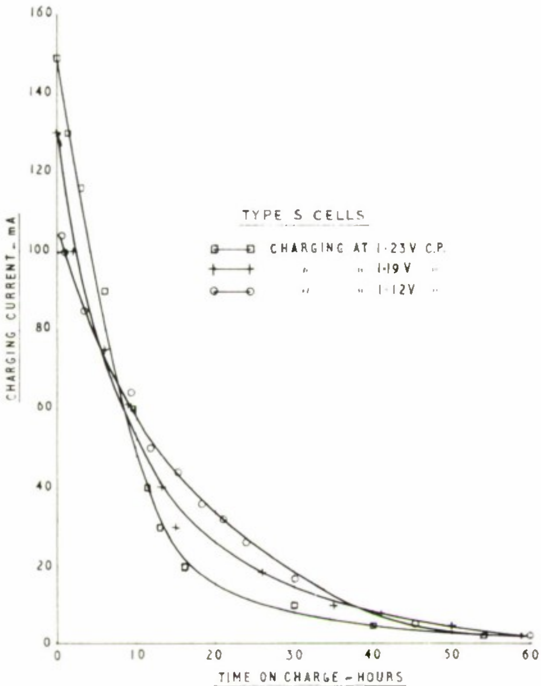

FIG. 5. Charging curves for Lead-Silver Oxide Cells at constant potentials of 1·12v, 1·19v and 1·23v/cell.

The long time required for charging and the increased output obtained after charging at higher potentials, compare Fig. 4 with the 25 ohm line of Fig. 6, suggested that it would be of interest to investigate a wider range of charging conditions. A few tests were therefore carried out with constant current charging and others at a constant potential of 1·30 V/cell.

Discharge Tests

Preliminary discharge tests were carried out at 20 $\pm$ 5°C through separate fixed resistors of 5, 10, 20, 25, 35, 45, 50 and 100 ohms on cells which had been charged at 1·12 V for 72 hr. From the results of these tests, some of which are shown in Fig. 6, loads of 50 and 20 ohms were selected for use in further tests; full output with little polarization was obtained on the 50 ohm load, whilst the slight fall in mAh output and appreciable reduction in discharge voltage on the 20 ohm load suggested that this was close to the maximum load which the cell could sustain without marked reduction in performance.

Tests on these loads on cells charged at the three values of constant potential were then carried out at 20, 0 and -20°C; some tests at -10°C on a 20 ohm load were also carried out after the tests at the first three temperatures had been completed.

Tests on cells after storage were carried out at 20°C on the 50 ohm load.

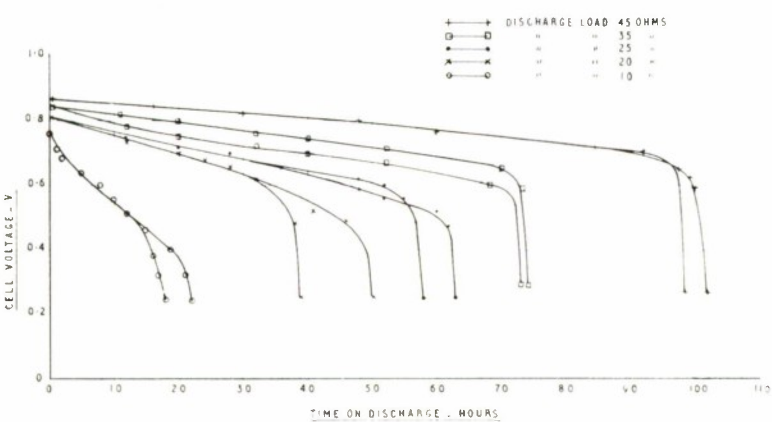

FIG. 6. Discharge Voltage-Time curves for Lead-Silver oxide cells charged for 72 hours at 1·12 V/cell. Effect of discharge load at 20°C.

Storage Tests

Cells were stored, unprotected, in open trays as follows:

(i) in temperate storage, storage under normal Laboratory conditions at 20 ± 5°C, uncharged for six months and for nine years;

(ii) in temperate storage, charged, for six and 12 months;

(iii) in "desert" storage, storage at 50 ± 2°C for six hours a day, four days a week and at 20 ± 5°C during the intervening periods, uncharged, for three months, one year and two years;

(iv) in "desert" storage charged, for three and six months.

At the end of the storage periods the charged cells were discharged at 20 ± 5°C through separate 50 ohm resistors, whilst groups of uncharged cells were charged for 72 hr at each of the three constant potentials and then similarly discharged.

Charge-Discharge Cycling Tests

Preliminary cycling tests were carried out in which the cells were discharged to zero volts on constant resistance loads and recharged at 1·12 V/cell for 72 hr.

More extensive tests were carried out on cells after nine years temperate storage when the following cycling programme was set up, starting in each case with groups of six fully charged cells:

(i) 8 hr discharge through separate fixed resistors of 25 ohms, 15 hr charge at 1·19 V/cell;

(ii) 16 hr discharge through separate fixed resistors of 25 ohms, 24 hr charge at 1·19 V/cell;

(iii) 24 hr discharge through separate fixed resistors of 25 ohms, 36 hr charge at 1·19 V/cell.

After every tenth discharge the cells were charged for 48 hr at 1·19 V, discharged through separate fixed resistors of 25 ohms to a final on-load voltage of 0·5 V/cell, recharged for 48 hr and then put back on their respective cycling routines. A further group of six cells was subjected to a routine of 24 hr discharge through separate fixed resistors of 25 ohms, 30 hr charge at 1·30 V/cell, for 10 cycles only.

Discussion

When considering the results of the tests it is essential to bear in mind that, except for the cycling tests, a fresh cell was taken for each test. Patterns of cell behaviour may, therefore, be deduced from the work, but direct comparisons, of for example outputs after storage with those obtained immediately after charging cells when new, can not be made.

From Fig. 3 it is apparent that at a low constant current the cell will accept a charge of about 1500 mAh before its voltage rises to a value of about 1·3, at which point the higher oxide of silver presumably begins to form. Reference to the discharge curves of Figs. 7, 8 and 9 shows that in fact the value of 1500 mAh corresponds closely to the output obtained from a cell on a 50 ohm load. However the constant potential charging curves of Fig. 5 show that even at 1·23 V, which is close to the maximum value which can be used without the risk of forming the higher oxide of silver, about 60 - 70 hr are required to achieve an input of 1500 mAh. The input during the first 10 hr is about 1000 mAh and about 1200 mAh after 15 hr. It is, therefore, the last 20 per cent of charge which requires the major portion of the charging time. At lower charging potentials the input during the early stages of charge is reduced but by about 20 hr the input is similar for all three of the values tried. This conclusion is confirmed by the results given in Table 1 for the durations of discharge obtained from cells charged for times between 15 and 30 hr at 1·12, 1·19, or 1·23 V respectively. It is thus apparent that the inability to charge the cell rapidly is one of its limitations.

TABLE 1.

Effect of Time on Charge at Constant Potential on Discharge Duration.

Charging Potential	Charging Time Hours				
	15	20	25	30	72
	Discharge Time, Hours, to 0·6 V on 50 ohm Load at 20°C				
1·12	67	87	82	92	100
1·19	74	89	98	92	108
1·23	84	88	94	93	110

Constant current charges at 150, 100 and 75 mA for 10, 15 and 20 hr respectively, equal to the nominal 1500 mAh capacity of the cell, all resulted in discharge durations of about 50 hours on a 25 ohm load and in each case the initial part of the discharge took place at the voltage level, 0·9 to 1·2V, of the higher oxide of silver. The duration of this initial stage increased, rather unexpectedly, with decrease in charging current, from 40 minutes at 150 mA constant current charge to 150 minutes at 75 mA. This suggested that rapid charging with minimum higher oxide formation might be achieved with higher charging currents. However in all these constant current charges cell voltages were above 1·45 for several hours, and in earlier constant current charges at 12 mA it had been found that when cell voltage rose above 1·3, the third step in the charging curve of Fig. 3, cells began to swell and eventually became open circuited as a result of internal gas pressure. Cells were also swollen after constant potential charges at 1·4 V/cell. It would appear, therefore, that 1·3 V is a practical limit to cell voltage on charge and that consequently it is not advisable to attempt rapid charging at constant current.

It is possible that constant potential charging at 1·30 V/cell may be a better approach to this problem, but this still remains to be investigated as the charging equipment at present in use limits the current at this potential to less than 1 A and it is known that initially the cell will accept a higher current than this.

The discharge performance of cells charged for 72 hours at 1·3 V/cell but subject to this current limitation is shown in Fig. 13 and comparison with Figs. 7, 8 and 9 shows an increase in output of about 50%. However advantage of this extra output can only be taken if a discharge at two voltage levels is acceptable.

The effects of load and temperature on the output of the cell are shown in Figs. 6 to 12, which are average results for groups of five cells. At normal temperature the full output of approximately 1500 mAh is obtained up to a load of about 20 ohms, the 40 hr rate, but on a 10 ohm load the output falls by about one third (Fig. 6). Similarly, although the discharge voltage is progressively decreased as the load is increased, this depression becomes severe at the 10 ohm loading. The second limitation of the cell is therefore that it is only really suited to low rates of discharge, 40 hr rate or lower.

Figures 7, 8 and 9 show that on a 50 ohm load discharge durations at 20, 0 and −20°C are similar and the voltage level obtained at 0°C is only slightly lower than at 20°C. At −20°C, however, the discharge voltage is appreciably reduced, and in addition a few cells gave a significantly lower output than others, as indicated by the dotted line in Fig. 8, whilst others showed a marked drop in voltage after about 20 hr on discharge followed by a recovery after about 40 hr. It is probable therefore that −20°C is the lower limit for operating on a 50 ohm load. On a 20 ohm load, Figs. 10, 11 and 12, there is a marked drop in voltage, but not in discharge duration, on discharge at 0°C by comparison with 20°C. The lower temperature limit at this load appears therefore to be about 0°C as performance deteriorates considerably below this value.

Charging voltage appears to have little effect on discharge performance, apart from the fact that cells charged at 1·12 V generally have slightly shorter discharge durations than cells charged at 1·19 or 1·23 V for which the discharge times are similar.

The effects of storage on charged cells are shown in Table 2, from which it is apparent that storage in temperate conditions for 52 weeks or desert conditions for 26 weeks does not cause drastic deterioration in output. The most significant findings are an increase with storage time in the number of cells which give only 70 - 80 per cent of the output to be expected from freshly charged cells, and in the number of cells which instead of showing a sharp fall in voltage at the end of discharge have a long, slowly falling, voltage "tail" which may take 5 to 15 hr to fall from 0·6 to 0·2 V. Expressed in a more positive way, after 52 weeks temperate storage or 26 weeks desert storage about half the cells gave outputs within about 10 per cent of that of freshly charged cells. Apart from the fact, already noted for cells tested immediately after charging, that cells charged at 1·23 or 1·19 V again gave longer discharges than cells charged at 1·12 V, no significant differences are apparent between cells charged at the three different potentials.

The results of tests on cells stored uncharged are given in Table 3. Temperate storage for nine years or desert storage for one year is without any apparent effect on cells which are subsequently charged and immediately discharged. After two years desert storage a few cells gave outputs which were only about 80

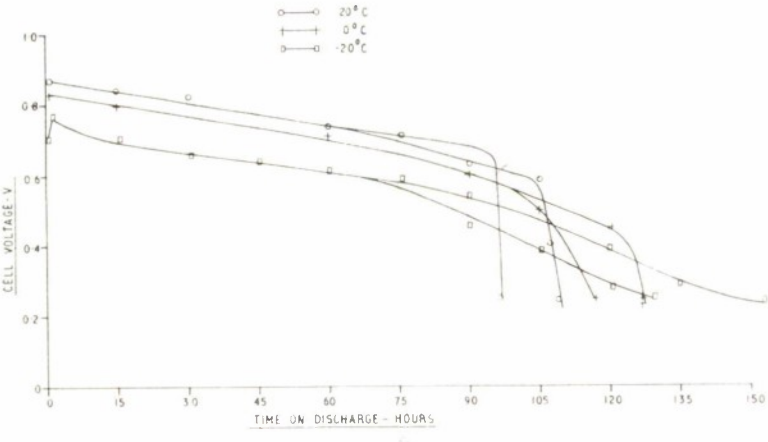

FIG. 7. Voltage-Time curves for Lead-Silver Oxide Cells charged for 72 hr at 1·12v/cell on 50 ohms discharge load at 20°, 0° and −20°C.

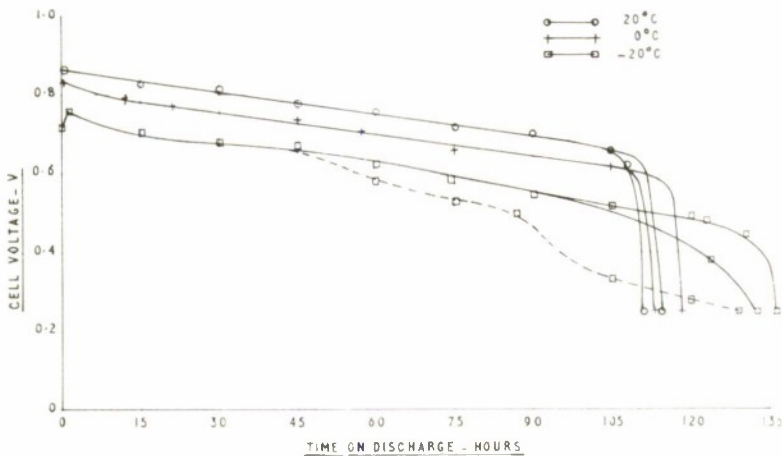

FIG. 8. As Fig. 7 but at 1·19v/cell.

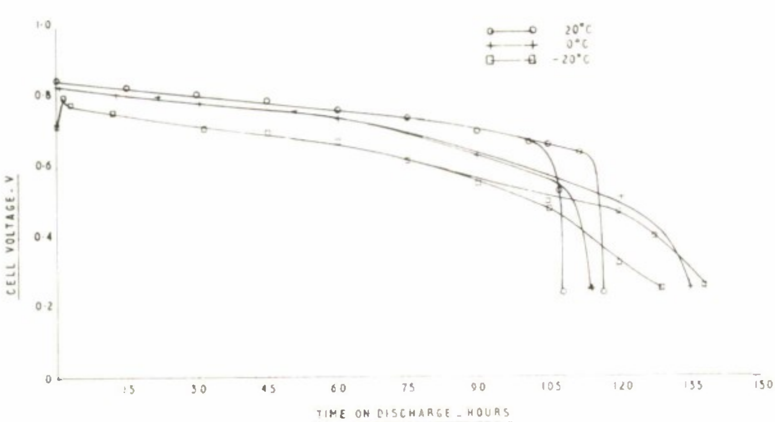

FIG. 9. As Fig. 8 but at 1·23v/cell.

per cent of that expected from freshly charged cells, but over 60 per cent were within 10 per cent of this value.

In further tests after nine years temperate storage, groups of cells were charged at 1·12, 1·19 and 1·23 V/cell and discharged on loads theoretically requiring from six to 52 weeks for completion of discharge. All cells gave the expected output durations and similar tests are now in progress on cells charged at 1·30 V/cell to determine whether the presence of the higher oxide of silver is detrimental to long duration low current discharges.

An attractive feature of the cells is their cleanliness. Of the several hundred cells tested, not one, even after the longest period of storage, showed any signs of carbonate encrustation around the grommet seal.

The initial cycling tests were attempted on a basis of 100 per cent discharge through 50 ohms and 72 hr recharge. The timing of these cycles proved to be difficult to control and, in spite of attempts to overcome this difficulty by using different discharge loads, cells were frequently discharged to zero volts and overcharged for several hours. Because the current is so small in the final stages of charge, overcharging for a few hours is unlikely to be harmful, but frequent discharges to zero volts are probably harmful to pressed powder electrodes. This test was therefore stopped after the tenth cycle when although outputs were down to about 50 hr to 0·6 V on a 40 ohm load, approximately 1000 mAh, rechargeability had been established.

The tests on cells after nine years temperate storage in which they were cycled at approximately 15, 30 and 50% depth of discharge (referred to a nominal capacity of 1500 mAh) by charging and discharging cells individually for fixed periods of time were terminated after 40, 20 and 20 cycles respectively because of pressure of other work. The results of these tests are summarised in Table 4 from which it will be seen that although output drops during the early cycles, it shows a subsequent tendency to stabilize at about 1000 mAh and at this output level all cells were satisfactory and showing no signs of failure when the tests were ended.

The ability of the cells to withstand repeated charge-discharge cycles was further demonstrated when, after standing idle for about 12

TABLE 2.

Effect of Storage on Discharge Duration. Cells Stored Charged.

Charging Potential	Storage	Discharge Time, Hours, to 0·6V on 50 ohm Load at 20°C				
1·12	Nil	91	94	100	101	102
1·19	Nil	107*	108	108	109	112
1·23	Nil	99*	104	104	114	116
1·12	Desert 12 weeks	93	94	100	101	102
1·19	Desert 12 weeks	103	104	104	104*	106
1·23	Desert 12 weeks	99*	104*	107*	109*	110*
1·12	Desert 26 weeks	91*	100	101	103	104
1·19	Desert 26 weeks	74	74	78	81*	93
1·23	Desert 26 weeks	93*	93*	102*	103	110
1.12	Temperate 26 weeks	88	90*	93*	94	90
1.19	Temperate 26 weeks	80*	98*	100	100	100
1·23	Temperate 26 weeks	42*	97*	104	104	105*
1·12	Temperate 52 weeks	80*	81*	82*	87	99
1·19	Temperate 52 weeks	93*	95	98	99	108
1·23	Temperate 52 weeks	56*	91	98	100	101

* Indicates a long voltage "tail".

TABLE 3.

Effect of Storage on Discharge Duration. Cells Stored Uncharged and Subsequently Charged and Discharged.

Charging Potential	Storage	Discharge Time, Hours, to 0·6V on 50 ohm Load at 20°C				
1·12	Nil	91	94	100	101	102
1·19	Nil	107*	108	108	109	112
1·23	Nil	99*	104	104	114	116
1·12	Desert 12 weeks	83	95	103*	106*	107*
1·19	Desert 12 weeks	105*	105	107	108	112
1·23	Desert 12 weeks	104	105	105	108*	110
1·12	Desert 52 weeks	88	90	104	104*	108
1·19	Desert 52 weeks	99*	101	102	107*	108
1·23	Desert 52 weeks	102*	108*	111	112	113
1·12	Desert 104 weeks	79	86	100	109*	110
1·19	Desert 104 weeks	85*	102*	106*	107	111
1·23	Desert 104 weeks	69	84	109	115*	116
1·12	Temperate 26 wks.	97	98*	100	101	104*
1.19	Temperate 26 wks.	101*	102	104*	105*	107
1·23	Temperate 26 wks.	109*	110	111*	114	115
1·12	Temperate 480 wks.	86	90*	95	101	104
1·19	Temperate 480 wks.	97	104	104	105	107
1·23	Temperate 480 wks.	100	103	104	106	112

* Indicates a long voltage "tail".

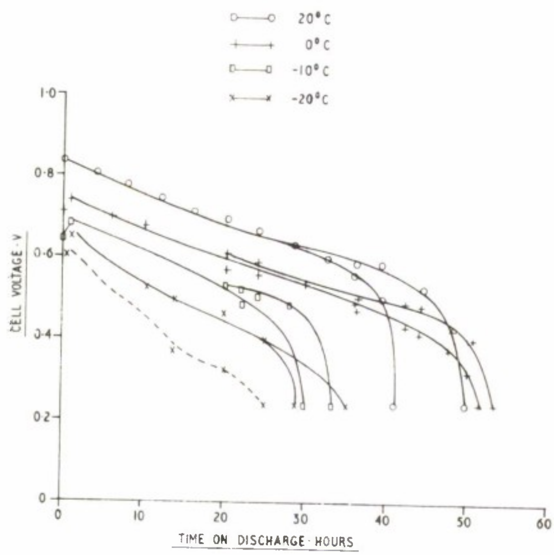

FIG. 10. Voltage-Time Curves for Lead-Silver Oxide Cells, charged for 72 hr at 1·12v/cell on 20 ohms discharge load at 20°, 0° and −20°C.

weeks, these same cells were again put on cycling tests. This time, however, the cells of each group were connected in series and the tests were carried out automatically, with infrequent manually controlled tests to measure output, to the following routine.

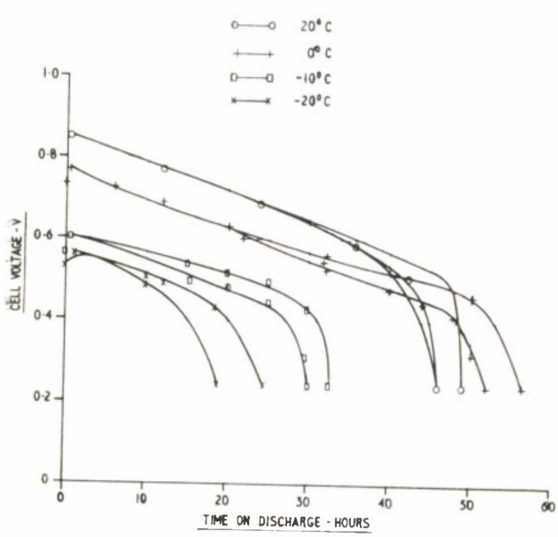

FIG. 11. As Fig. 10 but at 1·19v/cell.

Group

(a) 8 hours discharge through 150 ohms, 16 hours charge at 6 × 1·23 V.

(b) 16 hours discharge through 150 ohms, 32 hours charge at 6 × 1·23 V.

(c) 24 hours discharge through 150 ohms, 48 hours charge at 6 × 1·23 V.

This procedure would be expected to cause premature failure of some cells because the possibility of overdischarge and overcharge (at voltages above 1·23 V) arises due to the effects of differences in capacity, internal resistance and charge acceptance of the individual cells in each series connected group.

In fact all the cells of group (a) are still on test having completed a further 60 cycles (total of 100 including the earlier test) and are giving output durations in the range of 32 to about 50 hours.

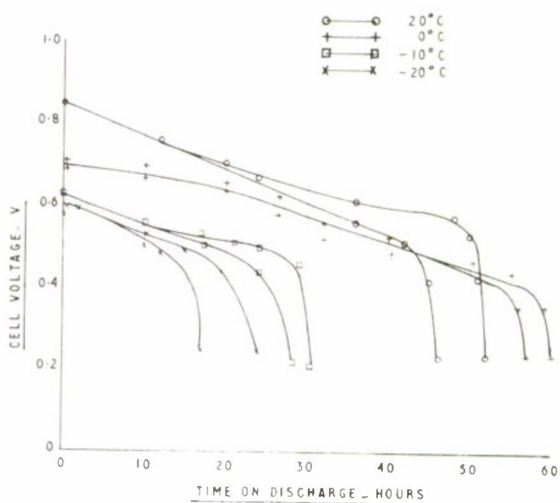

FIG. 12. As Fig. 11 but at 1·23v/cell.

Output durations of group (b) ranged from 30 to 48 hours on the 34th cycle (total of 54 cycles) but on the 35th cycle three cells developed internal short circuits and the test was stopped.

All the cells of group (c) are still on test after a further 20 cycles (total of 40 cycles), but discharge times range from 30 to 72 hours and it is apparent that some cells are being charged to the higher oxide level since discharge durations in excess of 50 to 60 hours can only be obtained if the extra capacity of

this oxide is available. Assuming that the presence of the higher oxide has a harmful effect on cell separators and barrier layers, then these cells will fail soon.

The cells cycled individually on a 24 hours 25 ohm discharge — 30 hours charge at 1·30 V/cell routine, completed 10 cycles satisfactorily without any apparent deterioration in a period of about four weeks. None of the cells showed any sign of swelling during this test. It is reasonable to assume therefore that the use of this higher charging voltage is without sudden disastrous effects.

TABLE 4.

Results of Charge - Discharge Cycling Tests on Cells after Nine Years Temperate Storage.

(a) 8 hr discharge—15 hr charge at 1·19 V

Voltage at 8 hr cycle 1	0·83	0·74	0·78	0·74	0·75	0·74
Voltage at 8 hr cycle 10	0·71	0·74	0·74	0·66	0·67	0·68
Output hours to 0·5 after 48 hr charge at 1·19 V	40	42	44	42	41	43
Voltage at 8 hr cycle 11*	0·77	0·72	0·73	0·71	0·71	0·70
Voltage at 8 hr cycle 20	0·70	0·70	0·73	0·73	0·70	0·72
Output hours to 0·5 V after 48 hr charge at 1·23 V	33	35	36	35	34	36
Voltage at 8 hr cycle 21	0·78	0·72	0·73	0·76	0·71	0·74
Voltage at 8 hr cycle 40	0·79	0·79	0·81	0·80	0·80	0·81
Output hours to 0·5 V after 48 hr charge at 1·23 V	31	33	34	33	31	29

(b) 16 hr discharge—24 hr charge at 1·19 V

Voltage at 16 hr cycle 1	0·76	0·78	0·74	0·78	0·75	0·77
Voltage at 16 hr cycle 10†	0·76	0·74	0·76	0·74	0·77	0·64
Output hours to 0·5 V after 48 hr charge at 1·19 V	40	41	41	42	41	41
Voltage at 16 hr cycle 11	0·80	0·80	0·82	0·80	0·76	0·72
Voltage at 16 hr cycle 20	0·77	0·73	0·76	0·74	0·73	0·75
Output hours to 0·5 V after 48 hr charge at 1·19 V	32	32	33	36	32	35

(e) 24 hr discharge—36 hr charge at 1·19 V

Voltage at 24 hr cycle 1	0·77	0·80	0·71	0·68	0·69	0·75
Voltage at 24 hr cycle 10‡	0·69	0·77	0·71	0·60	0·67	0·71
Output hours to 0·5 V after 48 hr charge at 1·19 V	34	34	36	38	34	38
Voltage at 24 hr cycle 11	0·70	0·74	0·68	0·68	0·62	0·55
Voltage at 24 hr cycle 20	0·69	0·75	0·72	0·71	0·66	0·63
Output hours to 0·5 V after 48 hr charge at 1·19 V	34	38	29	38	35	31

* Charge voltage raised to 1·23 after cycle 10.

† Charging time increased to 30 hr after cycle 5.

‡ Charging time increased to 40 hr after cycle 5.

Conclusions

The results of tests after nine years temperate storage fully confirm the claims that the cell has a long storage life in the uncharged condition.

The storage life in the charged condition is also good, at least 70 per cent of full output will be obtained after 26 weeks desert or 52 weeks temperate storage. The cell is well suited to low current drain applications. The 40 hr rate is about the maximum for full output at 20°C, although the usefulness of this rate is limited to temperatures above 0°C. At the 100 hr rate, however, the useful working temperature range extends to −20°C.

Cells may be satisfactorily charged at constant potentials up to 1·23 V. Charging time is however rather long; about 60 hr are required for a full charge although charging is about 80 per cent complete in 15 to 20 hr.

Constant current charging is not recommended as it leads to cell voltages at which gas evolution occurs. This causes swelling and failure of the cells.

The higher oxide of silver is formed at a potential of about 1·30 V. This is believed to have an adverse effect on cell behaviour by oxidizing separators and barrier materials. However, it has been shown that a period of at least several weeks will elapse before any serious effects on cell behaviour become apparent.

If a discharge at two voltage levels can be accepted, charging at 1·30 V/cell results in a

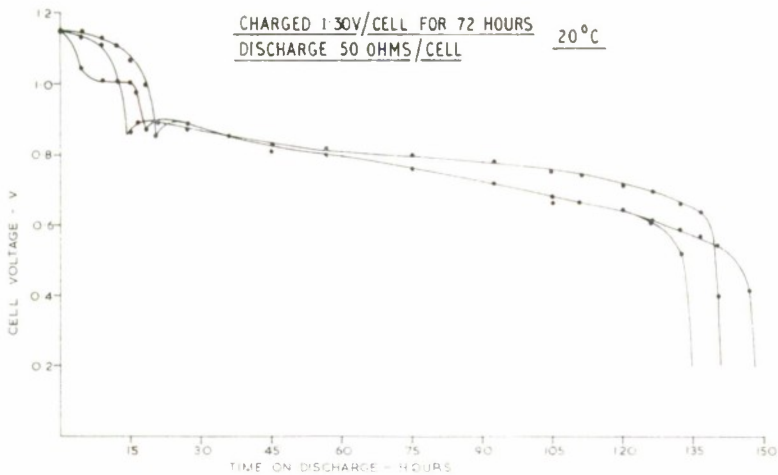

FIG. 13. Voltage-Time curve for Lead-Silver Oxide Cells charged for 72 hr at 1·30v/cell discharge load of 50 ohms/cell at 20°C.

useful increase in capacity, from 1500 mAh to over 2000 mAh. It may also lead to a useful decrease in charging time. This point, together with the effect of the higher charging voltage on long duration low current discharges is still under investigation.

The cell has been found to be capable of at least 20 charge-discharge cycles. The actual number will vary with depth of discharge and method of charging. Charging cells in series is undesirable as it reduces life and also causes cells to become out of step. Individual constant potential charging of cells remains the preferred method of charging.

Acknowledgements

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References

(1) U.S. Pat. 2,697,736.
(2) Standard Aqueous Electrode Potentials, de Bethune, A. J. and Swendeman Loud, N. A., Clifford A. Hampel Press. Illinois 60077, 1964.

BACTERIOLOGICAL INVESTIGATIONS ASSOCIATED WITH TRIALS OF THE BRABY 1200 DIESEL JACKET DISTILLING PLANT

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Abstract

The sea water inflow to the Plant was infected with a calculated dose of test organisms. Samples for bacteriological investigation were obtained from prepared sampling points during the distillation process, including the final distillate, and bacterial counts performed to follow the degree of destruction of the organisms at different temperatures and reduced pressure. It is concluded that distillates produced by this plant are bacteriologically safe.

Introduction

Distillation in polluted waters is a Naval requirement, but could present a hazard in the carry-over of potentially pathogenic organisms into the distillate. Although distillers have been capable of operating above 162°F (72·2°C), which was regarded as a safe temperature, Director General Ships Departments were interested in assessing the efficiency of Plants when distilling at low temperature and high vacuum. This type of distillation utilises an economical source of heat from diesel jacket water, and reduces scale formation within the plant.

The production of distillates free from intestinal pathogenic bacteria was investigated by the U.S. Public Health Service (1947), with a low pressure distilling plant, using crude sewage as a contaminant of the feed water, but their findings recommended a minimum distilling temperature of 165°F (73·9°C).

To assess the bactericidal efficiency of the distilling plant, the test organism needed to be non-pathogenic, easily differentiated in culture from naturally occurring sea water organisms, and yet represent pathogenic bacteria in their temperature requirements for growth, some cultural characteristics, and their thermal sensitivity.

Escherichia coli satisfied these requirements, and a strain isolated from a member of the Scientific Staff was used throughout the Distilling Trials.

The Braby 1200 Plant is of particular interest, as the sea water feed is boiled under a vacuum of 26 in. to 27 in. Hg., *i.e.* at between 46·1°C (115°F) and 51·7°C (125°F), which is well below the present mandatory minimum of 73·9°C (165°F), and the brine is not heated above the boiling temperature at any other point in the process. The brine in the evaporator corresponds to a concentration of salts approximately twice that of sea water.

Materials and Methods

The Distilling Plant

This is a hot water heated distiller, the necessary heat input being *via* a tube bundle situated in the lower part of the boiling vessel, with the heating medium inside the tubes, which are surrounded by boiling brine.

The vapour from the boiling brine passes through a monel metal demister, and condenses on the outside of tubes which have cold sea water flowing through them. After passing through the condenser tubes, the sea water flow divides, part going into the boiling vessel as feed, the remainder operating ejectors which remove air and surplus brine from the plant.

The brine/air/sea water streams combine and pass overboard.

Preparation of suspension of infecting organisms

A culture of the *E. coli* on a solid medium was emulsified with ¼ strength Ringer's solution (a balanced electrolyte solution for preservation of bacterial cells) and the number of bacteria estimated by comparison of the opacity of the suspension against a series of standard turbidity tubes. This suspension was then diluted to give the required concentration of organisms per millilitre, and a suitable volume used to infect the sea water inflow to the distillation plant.

Knowing the inflow rate as gallons/hour, and the total number of organisms to be injected during a specific period, a rough calculation was possible of the number of *E. coli* expected to be found per ml. of the infected water prior to distillation.

Bacterial counts

Water contains micro-organisms having different optimum temperatures of development. In general the natural water bacteria, *i.e.* those bacteria which are found more frequently in water than in any other situation, grow freely at temperatures between 20° and 30°C (68·0 - 86·0°F) whereas parasitic bacteria and those of soil and sewage origin (such as *E. coli*) tend to grow best in the neighbourhood of 37°C (98·6°F). Since these two groups of organisms vary in their sanitary significance, it is desirable to count them separately.

The sea water samples (prior to infection with *E. coli*) were cultured in Oxoid nutrient agar for three days at 20°C (68·0°F) to obtain a total viable count of naturally occurring water bacteria.

Water samples obtained from the distillation plant after infection of the sea water inflow, were cultured in MacConkey agar at 37°C (98·6°F), a medium in which *E. coli* is readily identifiable, and which is inhibitory to most of the heterogeneous sea water bacteria. The final distillate was cultured on sterile millipore polymeric membranes, after filtration of 25 ml. samples, at 37°C (98·6°F) for 48 hours.

1·0 ml. amounts of the samples, undiluted, and in various dilutions in Ringers' solution from 1 in 10 to 1 in 10,000 (according to the calculated number of organisms infecting the sea water inflow), were aseptically placed in sterile plastic disposable culture plates. Melted and cooled culture medium in 10 ml. amounts was added and the plates carefully agitated to mix the sample intimately with the culture medium.

Plate cultures from a range of sample dilutions were necessary in order to select those for bacterial counts that produced an easily countable figure of between 30 and 300 organisms from the original 1·0 ml. of sample used. Bacterial counts were returned as "Organisms per millilitre" of undiluted samples, and when it was considered useful, extraneous organisms appearing in the final distillate, were subjected to further cultural and bio-chemical tests to establish the genus.

Viability of *E. coli*

Two laboratory experiments were designed to assess viability under various conditions:—

1. In Ringers' solution at ambient temperature and at different population densities.
2. In sea water at 22°C (72°F) and 4·4C (40°F).

Ringers' Solution

In this solution, the proportions of the different salts are so ordered as to neutralise their individual toxic effects, and although superior to simple saline solutions, is not a perfect vehicle for transport of bacteria. Coliform organisms suspended in this solution for example, begin to die off at room temperature after two to three hours. At an initial concentration of 5×10^4 organisms/ml., the viable number after four days was reduced to 4% of this figure. At a concentration of $4{\cdot}5 \times 10^6$ ml., almost 50% were alive at the end of this period. It may therefore be concluded that the longevity of *E. coli* in Ringers' solution is influenced by the population density.

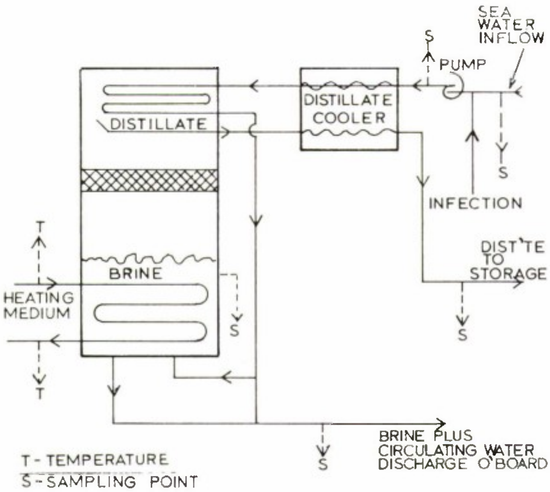

Fig. 1. Diagrammatic flow system of Braby 1200 Distilling Plant.

Sea Water

Two samples of sea water were infected with *E. coli* at a concentration of 5×10^3 organisms/ml. One was stored at room temperature (22·2°C - 72°F), the other in the refrigerator (4·4°C - 40°F). At the ambient temperature, no bacteria were alive after two days, while viable organisms were demonstrated at seven days under cold storage conditions.

Thermal Death Point of the infecting strain of E. coli

The thermal death point of a particular organism, is defined by Cruickshank as the lowest temperature that kills it under standard conditions within a given time. Under moist conditions it lies between 50°C (122°F) and 65°C (149°F) for most non-sporing organisms, and between 100°C and 120°C (212 - 248°F) for the spores of most sporing species.

Prior to further investigations, it was necessary to know the thermal death point in brine, of the strains of *E. coli* being used in the trials, and was found to be six minutes at 55·6°C (132°F).

Bacteriological Feasibility Studies

A laboratory still was assembled to simulate plant conditions regarding brine infection, temperature, and vacuum, and samples removed at intervals for plate culture.

The all-glass still, adapted for removal of brine samples while under vacuum, and for introduction of infecting organisms, was heated in a water bath whereas the Distilling Plant operates with a submerged heating coil. Control of heat and vacuum, and removal of samples therefore, posed more difficulty than would be encountered with the Trial Plant.

The Effect of Vacuum only on E. coli *in Brine*

At an ambient temperature of 18·3°C (65°F) and a vacuum of 27 in. Hg., the effect on the viability of the organism was compared with a similar test at ambient temperature and at atmospheric pressure.

The brine samples were inoculated with organisms to give a viable count of 8×10^4 per ml. prior to the test, and samples withdrawn for culture, at intervals from five minutes to one hour.

Under both sets of conditions, there was no reduction in the count of viable organisms.

The Effect of Vacuum and Heat

In the laboratory still, boiling brine at 47·2°C (117°F) and 27 in. Hg. vacuum, was inoculated with *E. coli* ($8{\cdot}5 \times 10^4$ per ml.) and samples withdrawn for culture at intervals throughout one hour. After 24 hours incubation, plate culture showed complete destruction within 10 minutes. Further incubation up to 14 days did not yield any viable organisms.

The Effect of Heat only

To assess the effect of heat at 47·2°C on the organism in brine at a concentration of $8{\cdot}5 \times 10^4$ per ml., without vacuum, samples were cultured as in the previous investigation. Viable organisms were still present after 75 minutes.

The results of the effect of vacuum + heat and of heat without vacuum, is shown in Fig. 2.

4. *The Effect of Rapid Changes of Pressure Without Heat*

To assess the effect of rapid pressure changes on the infecting organism without heating or boiling, the Braby 1200 distilling plant at Portland was run in the cold, and the sea water inflow infected with *E. coli* to give a concentration of about 4×10^4/ml.

Samples for culture were taken before the ejector (water pressure 40 p.s.i.) and after (approximately atmospheric pressure) with a vacuum of 26 in. Hg at the ejector throat.

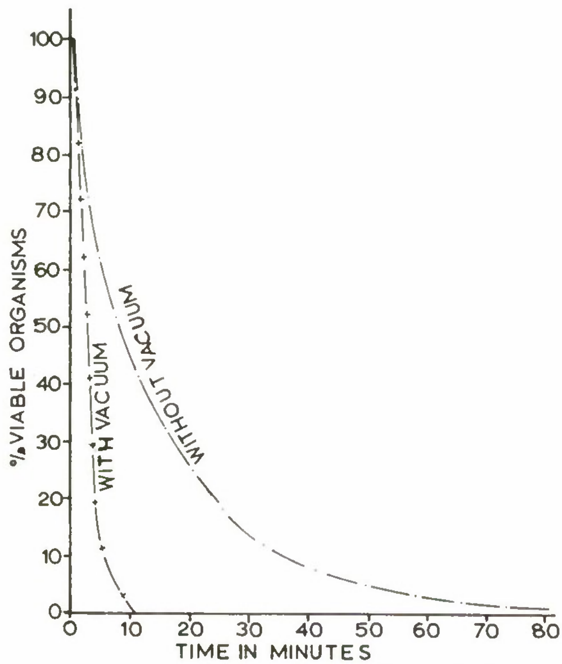

Fig. 2. Viability of E. coli at 47·2°C (117°F) with and without 27 inches Hg. vacuum.

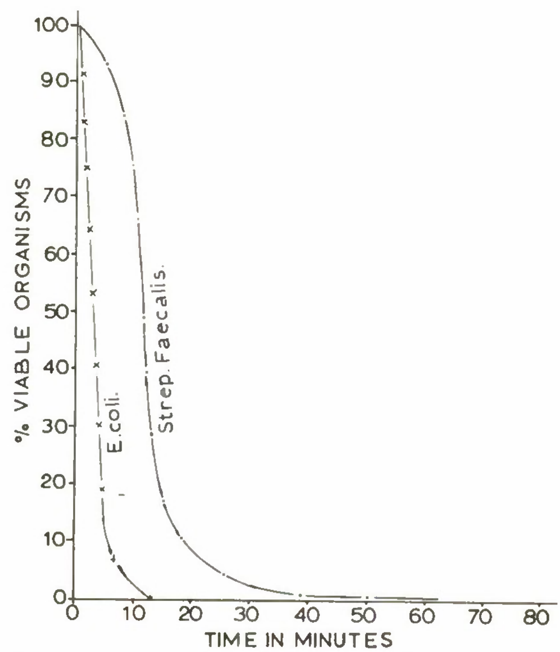

Fig. 3. Viability of E. coli and S. faecalis at 47·2° (117°F) and 27 inches Hg. vacuum.

The number of organisms cultured from the samples taken after the ejector, showed no reduction from the number present pre-ejector.

Introduction of a Heat Resistant Infecting Organism

After successful trials with *E. coli*, it was thought that an organism more resistant to heat than the strain of *E. coli* used, would more effectively demonstrate the efficiency of the distilling plant. *Streptococcus faecalis*, an inhabitant of the bowel, and therefore of sewage, appeared to be the organism of choice, with a known resistance to heat of 60°C (140°F), and the ability to grow on the media used for *E. coli* with easily recognisable cultural characteristics.

The precise Thermal Death Point in brine was defined by the same method used for *E. coli*, and was found to be one hour at 55·6°C (132°F).

In the laboratory distillation apparatus, boiling brine at 47·2°C (117°F) and 27 in. Hg vacuum inoculated with *Streptococcus faecalis* (5×10^4 per ml) and sampled for culture at intervals, demonstrated that a few organisms (0·01% of the original inoculum) were still viable after an exposure of one hour to these conditions, and Fig. 3 demonstrates the difference in heat sensitivity of the organisms *E. coli* and *S. faecalis*.

The Thermal Death Point and heat resistance of *S. faecalis* in brine being known, it was necessary to assess the viability of the organism in Ringers' solution under transport conditions, in sea water at ambient temperature, and under refrigerated conditions. A culture suspension of the streptococcus in Ringers' solution was prepared with the same concentration of organisms as supplied for a distillation trial, and the initial count of viable streptococci was found to have decreased by one third after four days under transport conditions.

The viability of the streptococcus in sea water was investigated as for *E. coli* at the same ambient and refrigerator temperatures, and with a similar concentration of organisms per ml.

The streptococcus demonstrated a greater resistance than *E. coli* to the lethal effect of sea water at both temperatures, and the comparison is shown in Fig. 4.

The greater resistance to heat, and to the lethal effect of sea water, and a higher survival

rate in Ringers' solution under transport conditions, indicated that *S. faecalis* would prove to be a more efficient indicator organism for the bactericidal efficiency of the distilling plant. In many of the trials this organism was used in place of *E. coli*.

Dose Limits of Infecting Organisms during Trials of the Distilling Plant

The average number of *S. faecalis* found in sewage and sewage effluent is, like *E. coli*, subject to great variation, but considered to be about 1000/ml in sewage and 100/ml in sewage effluent. The number of infecting bacteria introduced into the sea water inflow to the Plant represented massive contamination with sewage, and a wide range of pollution:

E. coli per ml of sea water	*S. faecalis* per ml.
49,000 - 430,000	3,000 - 30,000

Results

During 85 trial runs of the Braby 1200 Distilling Plant using either *E. coli* or *S. faecalis* as the infecting organism, on only two occasions, after concentration by membrane filtration were the indicator bacteria cultured from distillates. A small number (4 per 100 ml) appeared following a rise in the evaporator shell brine count, when the boiling temperature was 37·8°C (100°F). On the other occasion, the plant was priming heavily, and the distillate conductivity was very high, indicating carry-over of brine and organisms.

Rarely were the bacteria recovered from brine samples above 46·1°C (115°F) and then only in small numbers. This phenomenon, although more academic than relative to the production of a distillate free from potential pathogenic bacteria, was thought to be worth investigation.

The infected feed water containing 1 × 10^5 organisms/ml, cooled the distillate, and entered the evaporator at a rate of 100 gal/hr, where the temperature was 47·2° - 48·9°C (117 - 120°F) with a vacuum of 27 in. Hg. Although plate counts for the organisms on 1·0 ml amounts of evaporator brine samples from each trial run were carried out, and incubated under usual conditions for 24 hours, no infecting bacteria were isolated.

Concentration of 25 ml and 50 ml samples by filtration through polymeric membranes which were then cultured, proved negative, but

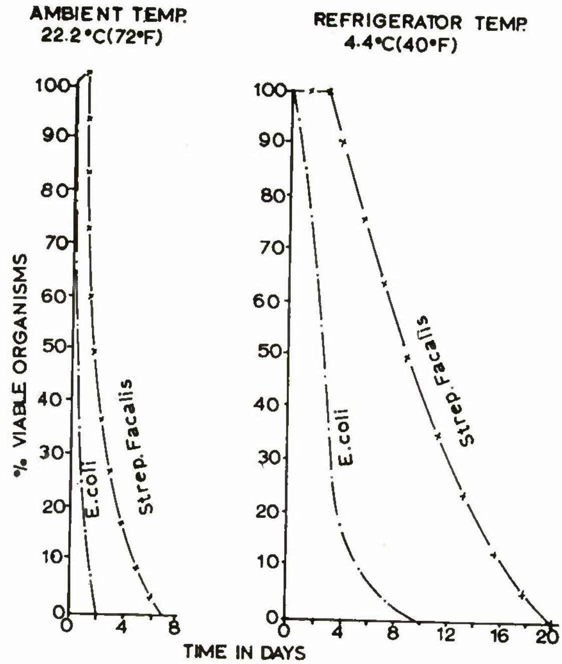

Fig. 4. Viability of E. Coli and S. faecalis in sea water at ambient and refrigerator temperatures.

on two occasions, 100 ml of brine investigated in the same way yielded one viable organism. As distilling temperatures were decreased below about 46·1°C (115°F) organisms were regularly cultured from the brine, the number increasing as the temperature was lowered, to thousands per ml at 37·8°C (100°F).

Distillates free from infecting organisms whether coli or streptococci, were consistently obtained at boiling temperatures down to 37·8°C (100°F), and also during a trial run with a sea water infection of 46 × 10^3 *E. coli* per ml, and a boiling temperature 35·8°C (96°F).

Filtration and concentration of the final distillates on polymeric membranes, although producing none of the indicator organisms, occasionally yielded cultures of saprophytic bacteria of the Genera alkaligenes and Bacillus subtilus.

None of the isolates were potential medical pathogens, and being a shifting population were assumed to be derived from the distillate tap which was open to manual and atmospheric contamination with ubiquitous organisms.

During the bacteriological examinations using membrane filtration followed by culture

on media containing inhibitory dyes, it was observed that dye cations were physically attracted to the membranes. This phenomenon was investigated and the findings published (Drake, Elgie and Nichols 1970).

Discussion In the early trials it was decided to compare the advantages of two types of organisms, and *Escherichia coli* and *Serratia marcescens* were chosen because of their recognisable cultural appearance, and the similarity of their Thermal Death Points, to those of many pathogenic bacteria. In the cultural methods used for the enumeration of the infecting bacteria, *E. coli* and *S. faecalis* were preferred as the most easily identifiable, and were used as indicator organisms after the first comparative tests.

It was also considered that an additional indicator organism of a spore-bearing type, could be usefully employed in these trials.

The potentially pathogenic sporing bacilli (anaerobes), are widely distributed in nature, but are for the most part essentially associated with the intestines of man and animals, though they may have their natural habitat in soil and decaying animal and vegetable matter. The spores, by virtue of their great powers of resistance, can withstand adverse conditions and survive for long periods in excreta, earth and water. They are constantly present in faeces, though generally in much smaller numbers than *E. coli*. The commonest type of these anaerobes is represented by *Clostridium welchii*.

Certain strains of these organisms can produce food poisoning, and are capable of resisting the temperature of boiling water for 1 - 3 hours. Nevertheless, there are many communities in England, consuming without apparent ill-effects, water which always contains spores of *C. welchii*. Moreover, it is more than probable that a far greater number of spores are ingested in milk, butter, ice-cream and other foods, than in water. It is considered therefore, that there is no reason to regard the presence of these and similar bacilli in water as harmful. although their absence is preferable (Thresh, Beal and Suckling, 1958).

Because of the apparent lack of evidence of their pathogenicity in water, and the possible difficulty in eradicating the spores from the distiller after each trial run, these organisms were omitted from the trials.

It was considered that in some inshore tropical waters there was a possibility of amoebic cysts being present in the sea water, and therefore capable of entry into the distillation plant. However, the thermal death point of these cysts is low, and an exposure to 50°C (122°F) for two minutes is considered lethal (Blacklock and Southwell). An exposure time and temperature therefore that will destroy the infecting organism, is capable of destroying amoebic cysts.

Experiments designed to assess the lethal effect of sea water on the organism during transport from Portland to the Institute of Naval Medicine, showed that an ambient temperature of 22·2°C (72°F) and a concentration of 5×10^3 organisms per ml, the *E. coli* were completely destroyed within two days, and the *S. faecalis* within seven days. Greatly improved viability of both organisms was obtained during a 24-hour transit period at low temperature in an insulated container.

In a laboratory low pressure distillation apparatus, simulating as nearly as possible plant conditions, 90% of the infecting *E. coli* were killed in four minutes, and totally within 10 minutes, but a small number of *S. faecalis* were still viable after an exposure of one hour.

It has been demonstrated that reduced pressure (27 in. Hg.) without heat, and rapid change of pressure do not affect the viability of *E. coli*, whereas boiling brine under vacuum is destructive for this organism and for *S. faecalis*.

In the laboratory, the test organisms used demonstrated Thermal Death Points (in brine) of 6 mins. at 55·6°C (132°F) for *E. coli*, and 60 mins. at 55·6°C for *S. faecalis*. It is difficult however, to account for the absence of viable organisms in the brine samples, under conditions which allow a massive inflow of infecting organisms into the evaporator, where the boiling temperature was between 46·1°C and 54·4°C (115°F and 130°F).

To assess a suitable degree of infection of the inflowing sea water to the distillation plant, large numbers of *E. coli* were initially used. In such concentration they were far in excess of the number of these organisms normally present in a sewage effluent.

The number of bacteria found in sewage and sewage effluent is subject to great variation, according to locality, method of treatment and temperature, but Thresh, *et al.* give the following as average figures for *E. coli:*

Sewage - - 100,000 *E. coli* per ml.

Sewage effluent - 10,000 *E. coli* per ml.

In view of this it was decided that an inflow dosage rate of around 30,000 *E. coli* per ml would more fairly represent sea water contaminated with sewage, and culture strengths were adjusted to approximate this dosage.

The first of the bacteriological trials commenced in the middle of May, and until the end of June the infected sea water inflow gave bacterial counts approximating the calculated dose.

As there are no laboratory facilities at the Admiralty Experimental Distilling Station, the preparation of *E. coli* cultures, and bacteriological examination of samples from the distillation plants were carried out in the laboratories of the Institute of Naval Medicine. With the transport available from Service sources, this involved four days' delay between despatch of cultures and examination of samples.

In the early trials, particularly during the warm summer months, there were occasions when viable *E. coli* were not demonstrated in the feed water, even after injection of calculated large doses of the organisms. It was considered that either the sea water and transport conditions at these higher temperatures, or the effect of the Ringers' solution upon the suspended organisms during the period of transit to Portland, was affecting their viability to the extent of complete destruction after a period of several days. Bacteria are strongly resistant to variations of osmotic pressure and there appears to be little evidence that salts such as those in sea water exert a germicidal action. However, the majority of fresh water bacteria soon perish in the sea, for great numbers of coliform organisms are discharged in sewage, but are not found more than a few miles from the outfalls, and pathogenic bacteria have only a short life in sea water.

Until experiments were initiated to determine the viability of *E. coli* in Ringers' solution, and in sea water during transport to the laboratory, it was suggested that refrigeration of samples coupled with more speedy transportation to enable bacteriological examination to be carried out within a few hours, would solve the problem. The truth of this was demonstrated in the week following two negative trials. By a fortuitous change in transport arrangements on this occasion, the specimen samples were examined bacteriologically within a few hours of sampling, instead of 24 hours later as had previously happened, and the results were satisfactory.

Ketchum, *et al.* (1949, 1952) investigated the death rate of coliform bacteria added to raw sea-water. The death rate was much reduced if the water was autoclaved or pasteurised, but increased if the untreated water was stored previous to the addition of coliform organisms. The production of coliform bactericidal substance by the natural bacterial flora was therefore indicated, and Coli and typhoid bacteriophages have indeed been found in harbour water, and in the sea off Plymouth (Harvey).

Mitchell and Yankovsky (1967) investigated the lethal effect of sea water on *E. coli* by studying the relationship between the size of the marine microbial population and the death rate of *E. coli,* using sea water concentrates of marine micro-organisms in differing population densities. Their results showed that the decrease in numbers of *E. coli* in sea water was strongly affected by the size of the marine microbial population. As the concentration of marine bacteria increased, so also did the rate and extent of death of *E. coli.* It was assumed that the nature of the lethal effect of seawater on *E. coli* would vary with seasonal and local changes of the environmental conditions.

The results of laboratory investigations demonstrated that the bacterial suspensions used to infect the feed water to the distillation plant, needed to be of a high concentration to allow for the reduction in the number of live organisms during the transport period. It was also essential to refrigerate the infected feed samples (sea water) to maintain the viability of the infecting organisms prior to culture in the laboratory. These precautions were incorporated in all subsequent trials.

Observations by many workers have recorded that bacteria which had been heated but not quite killed, required longer to germinate than unheated bacteria. It is generally concluded that, during the process of heating, the organisms are damaged in some way, so that their ability to multiply when subsequently transferred to suitable conditions, is adversely affected. The presence of viable organisms in culture after 14 days' incubation have been demonstrated, where none were evident after three days.

However, brine samples from the laboratory still, distilled under vacuum with heat, yielded no further organisms in culture after 14 days incubation, than after 24 hours.

It has been shown that boiling, albeit at low temperatures in high vacuum, is much more effective in bacterial destruction than non-boiling at the same temperature at atmospheric pressure.

It may be postulated that factors other than temperature and the physical effect of boiling brine on the organism, plays a part in their rapid destruction, and it is possible that complex enzymatic, osmotic, and protoplasmic changes occur under these conditions, leading to complete loss of viability.

This hypothesis is as yet unproved however, and it appears from the results of the investigation, that physical boiling is necessary for killing bacteria at relatively low temperatures.

Diesel Jacket Distillers present a remote possibility that the distillate may become contaminated with Ethanediol Antifreeze if a leak in the heat coil occurs, while leakage from the salt water cooled heat exchangers could infect the distillate when a vessel is distilling in potentially infected sea water.

For this reason it is proposed that investigations into the toxicity of anti-freeze additives be carried out and that the effectiveness of post-process sterilisers be assessed.

Conclusion

Distillates produced by this Diesel Jacket Water Heated Plant are bacteriologically safe, even at a boiling temperature as low as 35°C (95°F).

Acknowledgements

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References

Blacklock and Southwell. A Guide to Human Parasitology, 1938, p. 48.

Cruickshank. Medical Microbiology, 11th Ed.

Drake, W. J., Elgie, J. R., Nichols, G. (1970). Observations on the Effect of Membrane Filters on Inhibitory Dyes in Solid Media. J. Med. Lab. Technol. (1970), 27, 37-42.

Harvey, H. W. The Chemistry and Fertility of Sea Waters; 2nd Ed. p. 62.

Ketchum, B. H., Ayres, J. C. and Vaccaro, R. F. (1952). Processes contributing to decrease of coliform bacteria in a tidal estuary. Ecology, 33, 47.

Ketchum, B. H., Carey, C. L., and Briggs, M. (1949). Viability and dispersal of coliform bacteria in the sea. Limnological Aspects of Water Supply p. 64.

Mitchell and Schlomit Yankovsky. Nature 1967. Vol. 215, p. 891.

Thresh, Beale and Suckling. The Examination of Waters and Water Supplies. 7th Ed.

U.S. Public Health Service in co-operation with U.S. Maritime Commission. Report of study of Bacteriological Efficiency of Low Pressure Double Effect Distilling Plant.

OPEN DAYS at the ADMIRALTY WEAPONS ESTABLISHMENT

The **Admiralty Surface Weapons Establishment** on Portsdown Hill, Cosham, near Portsmouth, will be open to visitors during the week commencing June 28th, 1971. Admission will be by invitation. A Press Day will be held on Monday, June 28th and the general public will be able to apply for tickets for Thursday and Friday, July 1st and 2nd.

Displays have been arranged to show examples of ASWE's work concerned with all the Royal Navy's weapons used above the sea surface—guns, rockets and guided-weapons; radio and satellite communications; infra-red and other optical devices together with action information systems to aid the command. Research and development in such fields as radar, radio, electric and hydraulic power control systems, the display of information, computers and programming, optics and a great variety of techniques, both electronic and mechanical will also be exhibited.

As ASWE also gives technical advice on navigational aids, evaluates commercial equipments and seeks new forms of navigational aids for the Department of Trade and Industry, this field also will be presented.

The work of the **Admiralty Compass Observatory** (ACO) of Ditton Park, Slough, Buckinghamshire, now part of ASWE, is to be shown. ACO is concerned with research and development of navigation instruments and systems, associated projects include work for the Army and the Royal Air Force.

The Department of the Environment are displaying a range of their activities on behalf of clients, particularly the Royal Navy.

NAVAL RESEARCH AT THE PHYSICS EXHIBITION 1971

The fifty-fifth Physics Exhibition of Scientific instruments and apparatus, the first since the granting of a Royal Charter to the Institute of Physics, was held at Alexandra Palace, London, from 19th - 22nd April 1971.

The most conspicuous of the new developments this year was the large central stand organised by the Italian Federation of Scientific and Technical Associations. Apart from their display of new developments in instruments and apparatus, a special section was concerned with the history of physics in Italy and the career of a number of Italian physicists.

The level of participation by the various exhibitors from the U.K. was once again of a very high standard. The exhibits were shown in two categories, the first included those of the type normally displayed in recent Physics Exhibitions, having a marked content of originality. The second category included later developments of this type of exhibit illustrating the translation of ideas into commercially viable equipment. Most of the items on display were in the first category but there were quite a number to be seen which were obviously production models.

The arrangements for naval participation in this Exhibition were, as for many years past, organised by the Naval Scientific and Technical Information Centre and of the seven exhibits shown by the Naval R & D establishments, six were in the research or prototype category, the odd one out being an eddy current tester for non-ferrous metal tubes shown by the Central Dockyard Laboratory.

The assistance of Naval Technical Illustrators Pool once again enabled a very high standard of presentation to be attained.

Each of the separate displays were manned by members of the scientific staff of the five establishments taking part and those for whom it was a new experience, found it to be, because of the very knowledgeable audience which visited the Palace over the four days, a most rewarding, if somewhat tiring task.

Brief descriptions of the individual items displayed by the Naval R & D establishments follow.

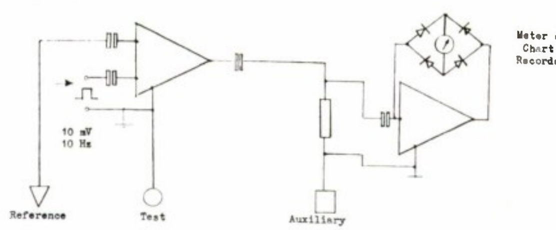


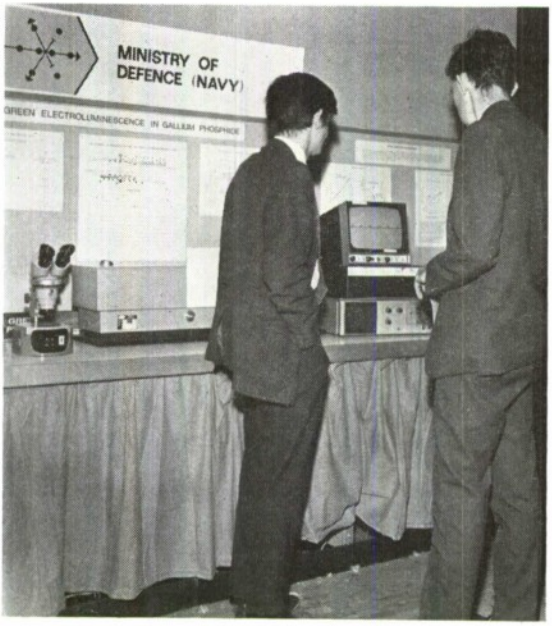
Fig. 1. Block diagram of the continuously recording corrosion monitor.

Central Dockyard Laboratory

Corrosion Monitor

The feasibility of using the Stern-Geary equation *J. Electrochem. Soc.*, 104 (1957) 56:

$$\left.\frac{\Delta E}{\Delta I}\right|_{\Delta E \to O} = \frac{K}{I}$$



Where $\Delta E/\Delta I$ = polarisation resistance, K = constant, I = corrosion current for the determination of corrosion rates of metals and alloys was demonstrated at the 1967 Physics Exhibition. For practical operation a probe containing three electrodes which act as the test, reference and auxiliary electrodes, is placed in the operating electrolyte in which it is desired to determine the corrosion rate of the material used for the test electrode. The operation of the Monitor is shown in block form in Figure 1.

When this probe is connected to the corrosion monitor the test electrode is alternated between a polarised and unpolarised state in a square wave form with respect to a reference electrode. This polarisation shift ΔE is maintained at 10 mV using a capacitively coupled differential amplifier as a constant voltage square wave source. One input of this differential amplifier is connected between the reference and the test electrodes, measuring ΔE, and the other input is supplied with a constant 10 mV square wave signal of frequency 10 Hz derived from a precise square wave source. The output current from this differential amplifier is proportional to the difference in signal levels at the input and this output current (ΔI), when capacitively coupled to the auxiliary electrode, is used as a feedback signal maintaining the polarisation shift (ΔE). Measurement of the feedback current (ΔI) gives a direct read-out of the corrosion current (I) which is related to the corrosion rate of the test electrode, and can be displayed on a meter or chart recorder. The use of integrated circuits has permitted construction of a robust corrosion monitor for industrial applications permitting online control.

Tube Tester

This equipment is a simple eddy current instrument reduced to the minimum of complexity for use as a tool by semi-skilled operators to examine non-ferrous heat exchanger tubes *in situ*. Conventional eddy current principles are employed but use is made of modern electronic developments to eliminate complex circuitry and reduce power consumption so that the instrument is battery operated and portable. The operating frequency is unusually high in this instrument to reduce the effective eddy current penetration to the thickness of the tube wall thereby avoiding picking up baffle plates or fins fitted to the external tube surface.

A probe containing two balanced coils fed with an AC signal is passed along the tube bore thereby inducing eddy currents in the tube wall. At a defect in the tube such as a corrosion pit or a stress corrosion crack the eddy current field is disturbed putting an AC bridge out of balance. The error signal is fed into a signal processing unit consisting of a wideband integrated circuit amplifier, level detector and pulse stretching unit, and a digital phase sensitive detector which gives a precise indication of the state of balance of the bridge whilst minimising errors due to noise.

The instrumentation suitable for incorporation in a robust housing for ship and factory application was exhibited.

Admiralty Compass Observatory

Squeeze-film Gas Bearings

Gas bearings operating on the squeeze-film principle were introduced into Britain from the USA by ACO about five years ago. Some practical work and a considerable amount of theoretical analysis had been carried out in America for some years previously, but the Navy Department interest is now concentrated on developing the technology and engineering of these bearings primarily for marine applications.

The application of this exhibit was concerned with low friction bearings for slow rotation devices such as are required in the gimbal bearings of gyroscopes and accelerometers used in navigational equipment and may supplant some conventional bearings and others requiring a supply of pressurised, cooled and filtered air to operate.

This class of bearing depends upon the vibratory generation of an above average ambient pressure between the bearing member surfaces. The necessary oscillatory motion is imparted to one of the bearing members by electromechanical transducers. The most convenient and least power-consuming are high Q piezo-electric crystals operating at the bearing system's resonant frequency. If the frequency of vibration is sufficiently high, viscous retardation of gas outflow and inflow on the compression and rarefaction cycles respectively and the non-linearity of the gas laws can be shown in theory and practice to give rise to a temporal pressure average above ambient. The load capacity of these bearings is estimated as about 35,000 Nm^{-2} (5 lb in^{-2}) of projected bearing area, dependent upon ambient conditions, although in instrument applications a high load capability may not be paramount.

The transducers used in squeeze-film bearings may be driven by self-resonating circuits or by an oscillator through a single stage amplifier.

In the two single-ended bearings which were shown, one conical (90° cone angle) and one slightly less-than-hemispherical, two lead zirconate titanate crystals were sandwiched between the bearing member and a countermass. Six external bolts pre-stressed the crystals to about 35×10^6 Nm^{-2} (5000 psi). The transducers were both of approximately halfwave design, supported at a central nodal plane, and vibrating in a longitudinal mode at ultrasonic frequencies (20 kHz).

The load capacities of both the conical and hemispherical bearings of projected area, about $2 \times 10^{-3} m^2$ (3 in^2), were about 4 kg (8 lb) with an input power of 10 W.

The double-ended bearing exhibited supported a mass which acted as a pendulum. Each half was similar essentially to the single-ended configurations in construction and operation. The countermass however formed a second bearing surface and the free members were connected by a central shaft to give the bearing stiffness perpendicular to the direction of axial vibrations. The bearing axial clearance was about 10^{-5}m (0·004 in).

The fourth item of the exhibit was an experimental instrumentation rig developed to assess the performance of squeeze film bearings. The bearing was driven through an amplifier by an oscillator of variable phase and frequency and the input voltage and current to the transducer were displayed on an oscilloscope and enabled power consumption to be determined. A photoelectric pick-up and a capacitance probe were used to monitor the transducer excursion and bearing lift respectively.

Services Electronics Research Laboratory

Gallium Phosphide Green Electroluminescent Displays

At the present time there is considerable interest in semi-conductor electroluminescent diodes. These diodes emit visible radiation when forward biased and arrays of diodes can be constructed to make display systems. For example, a matrix of 7×5 lamps can display a wide range of characters or symbols. These displays operate at a low voltage (approximately 2 V) and are compatible with semiconductor logic circuits.

Many semiconductor materials have been proposed for this purpose and red emitting displays of this form are readily available. However, at the present time gallium phosphide is the only material whose state of development permits both red and green emitting devices to be made. The technology and electrical characteristics of these devices are very similar so that it is now possible to make displays with interchangeable red or green emitting characters.

The SERL exhibit was divided into two parts:

Green-Emitting Gallium Phosphide P-N Junctions

Both the n- and p-type sides of the junction are grown using liquid phase epitaxial techniques. In addition to the donor and acceptor impurities used both sides of the junction are doped with nitrogen. This introduces a recombination centre with a transition energy very close to the band gap of gallium phosphide (2·2 eV) and green emitting diodes with a quantum efficiency of 0·1% can be made.

Static displays illustrated these epitaxial processes and the use of photoluminescence and

cathode luminescence in assessing the properties of the material produced. A working exhibit compared the spectrum of the green emitting diodes with that of the more widely known red-emitting devices.

Green-Emitting Gallium Phosphide Alpha Numeric Displays

Using a hybrid technology, 35 gallium phosphide diodes, arranged as a 7×5 matrix was bonded to a ceramic substrate. In these arrays each diode element operated at 2V, 10 mA with a brightness approximately 150 cd A^{-2} (approximately 450 ft lambert). The height of the character displayed was 0·8 cm and the device was designed to plug into a standard pitch (0·050 in.) socket or printed circuit board.

The exhibit demonstrated green-emitting arrays and compared them with similar red-emitting types.

Admiralty Materials Laboratory

Simplified Defect Location

This exhibit demonstrated the use of stress wave emission monitoring techniques for the location of defects in large engineering structures.

The emissions, which are elastic pressure waves generated within the material during the growth of a defect, often take place during the normal operational life of a structure, or may be induced by a proof loading. Piezo-electric sensors are used to detect these waves and discriminate between their arrival times to locate their source.

The equipment displayed included a prototype weld quality monitor, using only two transducers and a more sophisticated assembly which might ultimately be used with an online computer for realtime defect location on structures.

Admiralty Underwater Weapons Establishment

Measuring the Small Scale Roughness of the Surface and Bed of the Ocean

The two instruments described are designed to measure roughness profiles with much greater horizontal and vertical resolution than current wavebuoys and echo sounders can achieve.

The Directional Wavebuoy

The directional wavebuoy obtains sea surface statistics over a wide frequency range, with particular emphasis on the shorter gravity-controlled wavelengths (10 to 100 cm), and with provision for measurement of directional properties. Standard wavebuoys, which measure the slope of the sea surface, are limited in short wavelength response by physical size; the new buoy overcomes the problem of dealing with a large variation in dynamic spectral level by the use of two parallel measuring systems. The buoy, which is 2·5 m diameter, 2 m high and weighs 190 kg in air, consists of three parts: a tubular framework, an instrument pot and a stabilising fin assembly. Aluminium is used throughout for the buoy structure. Eight resistive probes are mounted vertically on the tubular framework to measure instantaneous wave heights relative to the buoy. The instrument pot contains a gyroscope with pitch, roll and vertical acceleration sensors, to monitor the buoy's motion. The fin assembly damps pitch and roll oscillations, and also acts as a sea anchor to maintain the buoy at the sea surface.

Thus long wavelength components of the sea surface are measured by the buoy's vertical motion, and short wavelength components by the probe array. In use the buoy is deployed from the parent ship on a buoyed electrical cable. A multi-track tape recorder is used for the analogue signals. The buoy has been used successively in sea states up to five. Spectral analysis of the results has been found to be feasible over the frequency range 0·1 to 15 Hz.

The Deep Towed Echo Sounder

The deep towed echo sounder is intended to improve on the horizontal resolution of conventional echo sounders, which is of the order of 50 m in 100 fathoms of water. It does this by operating within three metres of the sea bed. It consists of a short range echo sounder and a pressure transducer in a free-flooding housing.

The echo sounder is a commercial small-boat instrument, operating at 176 kHz, with range scales 0 - 32 ft and 0 - 32 fathoms. The beam width is 20°, and on the shorter range scale the pulse repetition rate is 16 Hz, pulse duration 0·4 m. The pressure transducer is of inductance type, with a frequency modulated output. The housing is a cylinder 1 m long by 30 cm diameter and overall weight is about 20 kg.

The assembly is suspended from a ship drifting at not more than two knots. A separate electric cable transmits the signals to the ship.

where they are converted to voltage output, amplified, filtered and summed, so that the vertical motion computed from the pressure transducer corrects the depth given by the echo sounder. In-built calibration units permit the system to be set up and checked before lowering the underwater housing. The system operates successively in water up to 100 fathoms deep. Resolutions of the order of 10 cm vertically and a metre or so horizontally have been attained.

Drag Reduction

The phenomenon of drag reduction in turbulent fluid flow, often known as the Toms phenomenon, has been studied with increasing interest in recent years. Some commercial applications are already appearing: for example the New York fire department is testing equipment utilizing drag reduction to achieve more efficient fire fighting techniques; drag reduction is used extensively in oil-well drilling, and experiments with crop irrigation are making headway.

In the Navy Department, experimental work in this field has gone ahead on the reduction of ship drag and on the study of the basic mechanism. Recently, a Royal Naval Coastal Minesweeper, H.M.S. *Highburton,* was fitted with an experimental fluid additive ejection system, and substantial reductions in drag were achieved. This work was carried out by the Admiralty Materials Laboratory and the Admiralty Experiment Works. At the Admiralty Underwater Weapons Establishment, high values of drag reduction have been obtained with low concentrations of asbestos fibres. This work may prove significant in ship applications, where the scale of turbulence is larger than in normal pipe flow work.

The apparatus demonstrated consisted of portable drag reduction measuring equipment for the rapid assessment of drag-reducing capability in samples of fluid, either collected during sea trials or during experimental laboratory programs. The demonstration showed the dramatic effect of adding a minute quantity of *Polyox* or asbestos dispersion to ordinary water.

NEW DIRECTOR OF ADMIRALTY UNDERWATER WEAPONS ESTABLISHMENT

Dr. G. L. Hutchinson the new Director of the Admiralty Underwater Weapons Establishment, was educated at Kings College, London University, and was awarded an Honours Degree in physics in 1935. He gained scholarships which enabled him to carry out research work into the ionosphere under Professor E. V. Appleton, and was awarded his Ph.D. in 1937. He then joined the lecturing staff at the College and commenced research into the electrical properties of materials at microwave frequencies.

The imminence of the war resulted in his becoming a member of the University teams which were employed at the U.K. coastal radar stations during the summer of 1939, and on the outbreak of hostilities he joined the Air Ministry Research Establishment. This establishment had pioneered the development of radar, first at Orfordness and then at Bawdsey, near Felixstowe. The establishment subsequently moved to Dundee where Dr. Hutchinson worked on radar aerial problems until the establishment was again moved, in April 1940, to Swanage.

At this time he was seconded to a new R.A.F. Organisation (60 Group) set up to install, maintain and operate the ground radar stations. Throughout the Battle of Britain he was employed in siting and setting up reserve radar stations around the south east coast and helping to install, and in many cases repair, the " permanent " stations. In 1942 he rejoined his old station, renamed Telecommunications Research Establishment, where he worked on various airborne radar and infra-red equipments but at the end of 1947 transferred to R.A.E. Farnborough as a founder member of the new Guided Weapons Department. His main interest in this department was the guidance of missiles, and particularly the problems associated with missile homing.

In 1953 he spent three months at the Administrative Staff College at Henley, and in 1954 was appointed SPSO in charge of the Guided Weapons Office at the British Joint Services Mission. At his first official function in Washington Dr. Hutchinson met his future wife and they were married later that year.

Although Dr. Hutchinson's responsibilities in the Washington Office covered liaison over the entire guided weapon field, the main U.S.-U.K. activity during the period was concerned with interchange of information on ballistic missile design, principally centred on the *Thor/Blue Streak* missiles. However early in 1957 he and Commander (now Rear-Admiral) P. G. La Niece were the first foreigners to have a presentation by the U.S.N. on the *Polaris* weapon and submarine system.

Returning to the U.K. in that year, he joined the staff at R.R.E. Malvern to take charge of research into defence against ballistic missiles, but his division also worked on radioastronomy and space. A large satellite tracking radar was built in-house and is now operated by the R.A.F. In 1963 he was apointed DCSO, Head of RRE's electronics research group and became Chairman of the CVD Technical Committees, a post he held for over six years.

At the end of 1967 he was promoted to CSO Deputy Director of RRE to take charge of all the project departments which covered guided weapons, airborne radar, and ground radar for the R.A.F., Army and Civil Aviation Air Traffic Control. He continued in this position until his transfer to AUWE in March, 1971.

CAPTAIN T. D. ROSS, R.N. (Retd.) — DIRECTOR ACO RETIRES

On 1 June 1971 the Admiralty Compass Observatory comes under civilian administration, a change which will coincide with the retirement of **Captain T. D. Ross,** R.N., as the last Naval Director of the A.C.O.

It was in 1838 that the increasing incidence of wrecks—due, it transpired, to the introduction of iron into ships—caused the Admiralty to appoint "The Compass Committee", to investigate the problem under the Chairmanship of Captain James Ross, later Admiral Sir James Ross the Arctic explorer. Their deliberations led to the formation of the Compass Department, which in 1917 moved to its present home, the Admiralty Compass Observatory, at Ditton Park, Slough, previously the home of Lord Montague. Since 1842 there have been only 12 Naval Superintendents/Directors in 129 years and it is fitting that Captain Ross, the great-grandson of a member of the original Compass Committee should be the last holder of this historic post.

Thomas Desmond Ross joined the Royal Naval College, Dartmouth in 1925 as a member of the St. Vincent term, passing out top, as a Cadet Captain, in 1928. After winning the Beaufort and Wharton testimonial in 1932 he specialised in navigation three years later and this has been his life ever since. His war-time appointments included those of Assistant Master of the Home Fleet and Staff Officer (Operations) Far East Fleet, and these were followed in 1946 by an appointment as Training Commander at H.M.S. *Dryad* where he was responsible for the formation of the experimental and trials section. As a Captain he held the posts of Director of Navigation and Direction and Deputy Director of Plans and finished his active service with 18 months in command of the cruiser H.M.S. *Birmingham*, retiring from the Navy in 1959 to go into industry.

Captain Ross joined the A.C.O. as Director in September 1961 when the S.I.N.S. project was still in its infancy and his 10 years in office have been years of continuous growth and activity. S.I.N.S. Mk. 1 is now fully operational and highly successful, while the Mk. 2 version is already well advanced; the Mk. 19 Compass/Stabiliser was introduced as the first of a family of modern gyro compasses with which the Fleet is now being equipped; the concept of the Central Stable Reference for the Weapons System has been introduced and responsibility for stabilisation in the Weapons Department has devolved upon the A.C.O.; the Polaris project required a considerable A.C.O. input; above all, for the first time the responsibility for the co-ordination of navigation systems has been placed with one authority, and this too has rightly devolved upon the A.C.O.

These changes, momentous in themselves in the life of a small establishment, have brought about increases in the responsibilities of all departments and have resulted in a doubling of the non-industrial staff during Captain Ross' tenure of office. It is due to his personality, guidance and example that all this has been achieved with complete harmony, so that the A.C.O. has lost none of its friendly "small ship" atmosphere and has continued to function as a lively and fully integrated unit.

Captain and Mrs. Ross have settled in East Meon in Hampshire where their many friends in both Naval and Civil Service will wish them a very happy, and probably a very active, retirement.

NOTES AND NEWS

A.S.W.E. and A.C.O. to Coalesce

As from 1 June 1971 the post of Director Weapons Navigational (Naval) will lapse and the work of the Navigation Directorate will be merged with that of Director of Weapons Research and Development Surface (Naval) and Director of Weapon Equipment Surface (Naval).

The Admiralty Compass Observatory will retain its present title and will be the headquarters of the Navigation Department of the Admiralty Surface Weapons Establishment. Certain work in the navigation field at present carried out at A.S.W.E. will come under the superintendence of the Head of this new Navigation Department.

The post of Head of the new department will be a professional functional post at D.C.S.O. level supported by a Naval Adviser/ Application Officer of the rank of Captain/ Commander R.N. Initially the post will be filled by the present Chief Scientist of the Admiralty Compass Observatory. He will be responsible to D.W.R.D.S.(N) for all the R. & D. work undertaken at the A.C.O. and for all matters of administration and security.

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Appointment of Chief Scientific Adviser

The Secretary of State has appointed Professor H. Bondi to succeed Sir William Cook, who has retired from the public service. Professor Bondi's title will be Chief Scientific Adviser and he will also succeed Sir William as a member of the Defence Council.

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Admiralty Research Laboratory

Mr. P. Lindop and Miss P. Ching attended the NATO conference on 'Scattering of Sound by the Deep Scattering Layer' and 'Reflection and Scattering of Sound by the Sea Surface' from the 29 March to 2 April at the Saclant A.S.W. Research Centre, La Spezia, Italy. Both presented papers at the conference, entitled 'Directivity and Reverberation from Scattering Layers' and 'Wind Effects in Shallow Water Acoustic Transmission'.

On receiving the British Acoustical Societies Annual Silver Medal at the Spring meeting held at the University of Birmingham, from 5 - 7 April, Dr. D. E. Weston's presentation address was entitled 'Intensity-range relations in Oceanographic Acoustics'. Other members of the Laboratory attending the meeting were Dr. J. Cook, Miss P. Ching and Mr. I. Smailes.

Three members of staff, Messrs. N. Wood, D. Morgan and S. D. Heany, are attending the second course on 'Military Operational Analysis and Research', at the Royal Military College of Science, Shrivenham, from 26 April to 16 July.

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Admiralty Surface Weapons Establishment

Dr. J. Croney is to be congratulated on his appointment as Visiting Professor to Southampton University's Department of Electronics thus further strengthening the links which already exist between the Establishment and the University.

Mr. M. L. Sefton, has recently returned from retirement as a part-time consultant. Another former colleague, Mr. L. E. Moxon, has returned from his travels in Australasia to take up a part-time appointment also, as a consultant in his specialist field of communications. Mr. B. P. Blaydes has been selected to attend the first course at the National Defence College in September of this year. Mr. R. F. Kyle is to replace Mr. H. M. Gilmour as Scientific Adviser (Radio and Radar) to the British Naval Staff in Washington whilst Mr. F. J. MacCulloch has been transferred to D.T.I. on promotion to P.S.O.

Messrs. J. Alvey, T. Mitchell and Captain G. Hayne from D.W.E.S.(N) at Bath visited the French Navy at Toulon recently to obtain information on the weapons system *Exocet* and also on the surface-to-air system *Mazurka*. As guests of the Captain they visited the *d'Ile d'Oleron*, an old ship which is primarily used for trials purposes. It is equipped with the main components of a *Mazurka* weapon system and is now equipped with an *Exocet* trials installation.

The Establishment is being given a "face-lift" by the Department of Environment by the planting of numerous trees and bushes. The four-hundred trees that they have planted so far will do much to soften the outlines of the buildings on the Portsmouth sky-line.

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John Edward James retired on 30 May 1971 after more than 26 years' service in the R.N.S.S. The whole of his working life has been devoted to the Royal Navy for he joined the T.S. *Mercury* in 1925 and a year later the Royal Navy as a Boy Seaman. He achieved Warrant Rank in 1935 and in 1939 was promoted to Lieutenant.

In May 1940 he was sent to Boulogne to cover the naval demolition parties prior to the evacuation, and there received wounds in both legs which resulted in him being invalided from the Royal Navy in July 1942. For his part in the Boulogne action he was awarded the D.S.C.

Mr. James joined the Royal Naval Scientific Service as a Temporary Experimental Officer in 1944 at H.M.S. *Excellent* for work on training devices, transferring to the Experimental Department in 1947.

In 1950 he commenced work on the Recording and Analysis arrangements which were to be installed in the Trials Cruiser H.M.S. *Cumberland* subsequently joining the ship as Officer in Charge of the civilian trials teams. He was promoted to Senior Experimental Officer in 1951 and continued to serve in H.M.S. *Cumberland* until 1954 when he returned to H.M.S. *Excellent* to work on the organization of trials teams and equipment for the *Seaslug* Mk 1 trials in H.M.S. *Girdleness*.

Promotion to Chief Experimental Officer came in 1956. He was quick to see the need for an efficient data processing and analysis organization to deal with the mass of data which would come from gunnery and guided weapon practices and firings and his initiative ensured that the equipment and organisation was available when it was required. He was also instrumental in the establishment of the Fleet Assessing Units which now contribute so much to the efficiency of naval gunnery.

Mr. James was honoured by the award of the I.S.O. in the Queen's Birthday Honours of 1970.

All his friends and colleagues in the R.N.S.S. will wish Jimmy and his wife a long and happy retirement but we are sure that his abilities and energy will soon find an outlet when he has settled down in his new home in the Isle of Wight.

Ben Smith, one of the Establishment's more colourful Senior Scientific Assistants, has just retired after nearly fifty years service to the Crown. His fifteen years' experience as a telegraphist in the Navy stood him in excellent stead in the R.N.S.S. where he carried out the first detailed analyses of the performance of long-distance teleprinter circuits. It was his careful analytical work which was later used as the groundwork for the development of the *I.C.S.* series of communications systems. He undertook a wide variety of assignments in the communications field during the course of his long career which led him to be one of the most widely-travelled members of the staff.

It is with deep regret that the news of the death of **Kay Milwright** was received by "Monty's" colleagues and friends at ASWE. Kay's long association with the Establishment has endeared her to many of the staff and her warm friendship will be greatly missed.

The death of **Arthur Lambert** occurred on 23rd April, 1971. Mr. Lambert had been Head of the Drawing Office at ASWE since 1952 and retired last July at the age of 60. His many friends in the R.N.S.S. will learn of his death with deep regret.

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The death of **Norman Henry Pudney,** Leading Draughtsman at ASWE occurred on 13th February, after a long illness. He was 50 years of age. The news of his untimely death at the early age of 50 will be received with deep regret by his many friends in the R.N.S.S.

Norman Pudney started his career as an electrical apprentice with John I. Thornycroft Ltd. in 1936 and joined A.S.E. at Haslemere as a temporary draughtsman in 1941. After the war he left to work in industry, joining E.M.I. Ltd. in 1947 but returned to A.S.W.E. in 1949. He became an established draughtsman in 1965 and was promoted to leading draughtsman in 1967.

Most of his work in A.S.W.E. had been in the installation division and it is in this field that he will best be remembered by so many people not only at A.S.W.E. but among those with whom he dealt in the Project Divisions and the Ship Dept. at Bath.

Our sympathy goes to his widow Florence who had also been employed at A.S.W.E.

The sudden death of **Stan Weychan** occurred on Wednesday, 21st April, 1971 while at his work at A.S.W.E.

Stan Weychan was one of the longest serving members of A.S.W.E., joining the Radar Development Group at Eastney Fort East in March 1941, having previously been with the G.P.O. He moved to A.S.R.E. at King Edward's School, Witley, in June 1942 where he was associated with radar modulator and transmitter development.

At the end of the war he joined the R.A.F. on National Service and then in 1948, U.C.W.E. at Havant. From 1956 - 1958 he was associated with sea trials on H.M.S. *Girdleness* after which he transferred to the valve division of A.S.W.E. where he was promoted to Senior Scientific Assistant in July 1962.

To all his friends and colleagues at A.S.W.E., Stan will be remembered as a willing and helpful member of the team. He was 50 years old and leaves a widow, two sons and a daughter, to whom we offer deepest sympathy.

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Admiralty Underwater Weapons Establishment

Captain J. S. Launders, D.S.O. and Bar, Royal Navy, has recently taken up his appointment as Director Weapons Equipment Underwater (Naval) at A.U.W.E. Portland, in succession to Captain D. M. H. Stobie, R.N.

Captain Launders is a submarine specialist, with a distinguished wartime record. He was awarded his first D.S.C. as First Lieutenant of H.M.S./*MP 35* for successful attacks on enemy shipping in the Mediterranean. The second D.S.C. and the two D.S.O's were awarded later when he was Commanding Officer of H.M.S. S/M *Venturer*. Among many other successful attacks he torpedoed and sank two U-boats in heavily patrolled Norwegian waters, the first inside the Lofoten Islands and the second in the Bergen Approaches. The latter is the only authenticated *SSK* attack on record.

For the last two years Captain Launders has commanded H.M.S. *Forth* and the 7th Submarine Squadron based on Singapore.

At the end of January 1971, Mr. H. A. Hudson of A.U.W.E., Captain T. Baird (Capt. M.C.M.) and Commander de Courcy of Ireland of D.N.W. attended the Minefield Conference held at the Naval Ordnance Laboratory, Silver Springs, Maryland, U.S.A. The theme of the conference was the Arctic Environment and Ice Cover in relation to mining and mine countermeasures operations in the North Polar regions. Some 300 delegates attended the conference, the U.K. and Canada being the only non-U.S. countries invited to attend. Topics covered included the northern ice cap, oceanography of the polar regions, signatures and analysis of *MCM* vehicles and operations, remote sensing, the acoustics of the environment, and operational studies. Papers presented by the U.K. representative dealt with the magnetic, acoustic and pressure signatures of hovercraft, and an analysis of British mine laying operations.

After more than 10 years of useful life, the Establishment's 803 computer has now been transferred to the R.A.F. satellite tracking station at R.R.E. Malvern and work has begun on housing the ICL 1904A computer which is due for delivery on 1st September.

Commodore N. P. Datta of the Indian High Commission visited on 16th February to see something of the working of the Establishment, with a view to setting up similar facilities in India.

Dr. E. J. Risness has rejoined A.U.W.E. on completion of a course at the Imperial Defence College, and has assumed the appointment of Head of the Torpedo Research Division.

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Central Dockyard Laboratory

John Bradley, Principal Scientific Officer, who retired from the Royal Naval Scientific Service on 1st April, 1971 after 29 years' service, undertook his early training in metallurgy at the Royal School of Mines. In 1934 he joined the new laboratories of the LMS Railway at Derby, and during this time he worked closely with Dr. Hugh O'Neill (now Professor O'Neill) who was quick to realise the very high qualities of thoroughness and dependability which John brought to his work. This included an extensive study of bearing metals and the development of the *Bradley Process* for the separation of bronze and white metal from mixed borings.

In 1942 he was seconded to the R.N.S.S. where his breadth of knowledge, range of techniques, and steady temperament were immediately recognised. He returned to the LMS only for the hour or two necessary to take away in marriage another popular member of the metallurgical staff, Margaret Saul.

Throughout his career in the R.N.S.S., John Bradley maintained a reputation as a fine all round metallurgist, although latterly he tended to concentrate on the complex area of copper-based alloys in which he is now recognised as a national authority. Throughout his service he maintained a reputation as a sound professional, but it is for the encouragement and training of more junior staff that he will be particularly remembered. In this respect he has left a strong influence on the metallurgical service to the Ship and Dockyard Departments, and his wisdom and patience will be reflected in the work of those who now succeed him.

At a farewell dinner party at the Bosham Hotel on 2nd April, some of his many friends gathered to wish him a long, and happy retirement, which he and his wife will no doubt fill with interest.

William George Beynon of the Central Dockyard Laboratory retired on 7th March, 1971 after 33 years Admiralty service.

Educated at the Gorveston Grammar School and later at the University College, Swansea, he obtained a B.Sc. Honours Metallurgy degree in 1933. After initial industrial experience at the National Smelting Co. Ltd., Avonmouth where he was involved in the production of 99·99% Zn by the then new refluxer process he entered Admiralty service in 1938.

His Admiralty service has been chequered and involved eight years at NOID Bragg Laboratory, Sheffield in which two years were spent in setting up and running an analytical outstation at Middlesborough. He took a teaching post as lecturer in metallurgy at the Northampton Polytechnic during 1946 - 7 before returning to the Bragg Laboratory. He transfered to AML Holton Heath in 1948 and in 1951 served as metallurgical adviser to the Naval Construction Department at Bath until taking up an appointment to set up and run a

laboratory at the Pakistan Naval Dockyard at Karachi. On his return he was successively executive adviser to E in C's Department, Bath and lastly a Principal Scientific Officer at the Central Dockyard Laboratory, Portsmouth with special responsibility for the metallurgical control of the foundry in which quality control procedures were established.

George Beynon has always been an easy colleague to work with and seems never out of sorts. In his younger days he took part in rugby football international trials and played for the Universities Athletic Union, Swansea. His hobbies are now mainly horticultural and he is content to leave car driving to his wife. His friends and colleagues at CDL and other MOD(N) establishments wish him and Mrs. Beynon a very long and happy retirement.

Southampton University have awarded a Ph.D. Degree to Mr. B. N. Hall for research into a high-strength copper-base casting alloy. The research was carried out mainly at CDL but using some of the university facilities. Dr. Hall, who joined CDL in 1961, took up a post in Scientific Advisers Section, Ship Department, Bath in May 1971.

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Directorate of Weapons Quality Assurance (Naval)

Wilfred Frank Maber retired from DWQA(N) Bath on 26th May, 1971, after a long and varied career commencing in 1927 when he joined the Royal Naval Cordite Factory as a laboratory assistant engaged on process control of naval gun propellants. During this period of his career he attended

Bournemouth Technical College and ultimately obtained a B.Sc. degree externally from London University in 1933. In 1932 he transferred to the Naval Ordnance Inspection Laboratory at Holton Heath and commenced his long association with CINO. In 1934 he passed the examination for ARIC and became an Assistant III (Carpenter Style) in 1936. During these years he quickly established himself as a first-rate analyst capable of tackling the problems posed by propellant explosive and non-explosive material in naval weapons. He also played an active part on the staff side of the local Whitley Council.

During the war he remained at Holton Heath and was promoted to Assistant II. At the post-war reconstruction he was regraded XO and was promoted to SXO in 1949 subsequent to his transfer to NOIL Caerwent in 1947. At Caerwent he followed his predominant interest in gun propellants, in particular the study of changes in the crystal size picrite at manufacture and during service. He contributed much in the adoption of the new closed vessel test for measuring rates of burning gun propellant. Also at that time he was associated with the Bedenham Investigation and contributed to the work of HTP in Ferry & Fancy HTP torpedoes. The advent of nuclear weapons resulted in his spending a year at AWRE in 1959 where he worked in the Applied Explosive Division. The knowledge he attained there stood him in good stead during the latter part of his career.

In 1961 he was promoted CXO and Head of Laboratory at NOIL Caerwent where he remained until 1967 when NOIL was wound up with the closure of RNPF and the laboratory work transferred to DCI (now DQA(Mat)).

In 1967 he occupied his latest post of Assistant to Scientific Adviser, CINO at Bath. Here his wide experience of materials and explosives in ammunition has been invaluable and as such wide experience is difficult to obtain in one individual he will be sadly missed. He has served on numerous committees and working parties on different weapons and has been very active in the last few months on problems associated with *Seaslug* Mk. II. He has also been connected with work on the Karl-Gustav 84mm and as a result of this activity has attended and contributed to symposia in Sweden on compatibility problems. Numerous other activities came under his control but the above gives some idea of the wide scope of his work.

Wilf, as he is known to his many friends, has been a keen photographer and philatelist and hopes to pursue these hobbies more

actively when he retires. After the war he was a Town Councillor at Wareham for two years and later at Chepstow was an active member of Toc H. In all this he combined an unassuming approach with a determination to do a good job and gained many friends throughout his career.

We extend to Mrs. Maber and Wilf our best wishes for a long and happy retirement and trust that their plans to settle in their native Dorset will be speedily fulfilled.

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Naval Aircraft Materials Laboratory

Commodore Spickernell, Deputy Chief Executive, Defence Quality Assurance Board visited the Laboratory on 26th February, 1971 as part of a visit to RNAY Fleetlands, when matters relevant to quality assurance were discussed in detail.

Mr. R. C. Clark, SEO, attended the 1971 meeting to ASCC Working Party 15, Aviation Fuels and Lubricants and Allied Products, in Melbourne, Australia from 24th March to 2nd April, as DGA(N) representative. There was, as usual, much exchange of information on research and development programmes, specification changes, Service problems, and attempts, some successful and others not, to achieve international standardisation of POL products.

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Naval Fuels and Lubricants Meeting

The 13th meeting between Britain, the United States, Canada and Australia, together with a New Zealand observer, on naval fuels and lubricants, was held in London, from 26th April to 30th April. The aims of the meeting, which is now held every two years by each country in turn, is to exchange information on technical developments in the field of petroleum fuels and lubricants, in relation to current and future naval requirements, by bringing together personnel of the navies, government departments and oil companies. The talks were first held in 1951.

Eighth G.M. Destroyer Commissions

H.M.S. *Antrim*, last of the eight *County* class guided missile destroyers to be accepted into service by the Royal Navy, commissioned at Portsmouth on Tuesday, March 30th. Armed with *Seacat* and *Seaslug* missiles, she is the third sea-going warship to bear her name, which in the last war was given to the R.N. trawler base in Belfast. The first commanding officer of H.M.S. *Antrim* is Captain H. W. E. Hollins, R.N. The destroyer was launched at the Govan shipyard of Messrs. Fairfield Shipbuilding and Engineering Co. Ltd. in October, 1967.

Oil Pollution

A conversation on the subject of oil was held under the chairmanship of Mr. D. R. Houghton at the Exposure Trials Station, Eastney, on 10th March, 1971 between the five laboratories concerned with marine sciences in the Solent Area.

Oil was chosen as the subject of this year's annual meeting because of the real risk of oil pollution in the area and the fact that the laboratories may well be asked to supply advice and assistance in case of accidents involving oil spillage.

Representatives attended from the CEGB Laboratory, Fawley, Portsmouth Polytechnic, Department of Biological Sciences and Marine Resources Research Unit, The University of Southampton, Department of Oceanography and Exposure Trials Station. Several members from the local authorities, Hampshire River Authority and The Institute of Petroleum were also present bringing the total to approximately 50 people.

The opening address was given by Mr. D. L. Griffiths, Superintending Scientist, C.D.L., and the speakers were Dr. L. H. L. Cooper, F.R.S., Instructor Commander J. Marsh, Dr. Molly Spooner, Dr. Sally Beastall and Mr. J. Wardley Smith. The subjects covered were a brief survey of oil pollution research in the U.K., the movement of oil slicks, natural erosion, dispersal and degredation of oil, the microbial decomposition of oil at sea and practical aspects of dealing with oil pollution.

In the afternoon visits were arranged to the exposure facilities and laboratories at ETS and in particular to the raft specifically designed for experiments in oil under natural conditions.

BOOK REVIEWS

Essentials of Optimal Control. By P. Naslin. Pp. 266. Iliffe Books Limited, 1968. Price £3·50.

The author's aim in writing the book is stated to be to bridge the gap between the modern theory of optimal control as developed by mathematicians with a bias toward mathematical sophistry and the needs of practical control engineers. Some 140 pages of the book are in fact devoted to the modern theory of optimal control stemming from the work of both Bellman and Pontryagin. The rest of the book is devoted to the more or less classical methods of "trial and error" and analytical optimisation using quadratic cost functions initiated by Wiener and mainly extended by Newton.

The English text is a translation by the author of his book originally written in French but with some additions to bring the book up to date. There is an addition to chapter two on practical optima which is essentially a reprint of the author's article in "Control" for September and October 1966 on the use of standard polynomials. The other additions — in chapter six — cover special items published by various authors in 1965. Thus the book covers the literature of the subject up to the beginning of 1967 and quotes 27 books and 25 articles.

Naslin is a well known writer in both English and French on a wide range of modern control topics, and teaches the subject in France. His own research appears to be concerned with the topics of the earlier chapters of the book and the later chapters on the more modern aspects of the subject are probably the result of experience in teaching the subject and making it more palatable to practical engineers.

There are six chapters in the book the first of which deals with a general discussion of optimal control theory as an introduction to the rest of the book. Chapter two gives a resume of practical optima based on frequency response methods, Bode and signal flow diagrams. This chapter also introduces some of the original work of the author in the field of characteristic polynomial transfer functions—called transmittances by the author who dislikes the usual nomenclature.

Inevitably there is a chapter devoted to probability theory, correlation functions, and power and energy spectra, topics which are essential for the chapter on optimisation with quadratic cost functions. This chapter is novel in introducing the two-sided Laplace transform. Two appendices on Fourier series and integrals and Fourier and Laplace transforms give the essential mathematics needed by the reader and there is a useful table of inversion integrals taken from Hudley (1964).

The chapter on quadratic optimisation of linear servo systems treats in essence the Wiener-Newton theory of such systems. Solutions are obtained as in the standard Wiener theory in the frequency domain by the technique of spectrum factorisation. The author expresses his indebtedness to the lectures of J. Hayes for the content of this chapter which also introduces the use of an operator due to P. Lefevre. As the author points out the main interest in these techniques is that they provide an analytical solution but the realism of such solution may be offset by the need to use that particular form of cost function.

Perhaps the most significant modern trend in optimal control is the use of two optimum principles—that of the principle of optimality by Bellman used in dynamic programming and that of the maximum principle of Pontryagin which stems from the classical work of Hamilton and Jacobi. Pontryagin's principle is probably less well known than Bellman's principle in Western Europe.

The treatment of these two topics is exhaustive and lucid at a level a little above an "introduction" but can be strongly recommended to anyone who wants to become acquainted with the more modern techniques. The fields of application and the relative merits of the two approaches are fully described and the book is a good addition to the literature of the subject. The whole book with its wide scope and lucid exposition can be recommended to engineers concerned with control problems.

R. A. M. Bound

Ultrasonics, Theory and Application. By G. L. Gooberman. Pp. xii + 210. London; English Universities Press Ltd. 1969. Price £2·25.

As an introduction to the subject of Ultrasonics, its properties and applications, this volume certainly contains sufficient material to set the enquiring mind off on numerous different tracks. Indeed it is possible that the scope should have been curtailed somewhat. Splitting a not over large volume into eleven chapters, in each of which enough ground is covered to produce a separate volume and more, reduces the text at times to a level of technical name dropping. This together with a mathematical treatment which varies widely in complexity makes for a state of mental breathlessness in the reader.

To be fair, this book is very readable and succeeds in the author's desire to give his readers adequate background knowledge to proceed to more detailed treatise. Unfortunately one can visualise students of a particular topic only reading a small part of this volume having, no doubt, the desire but not the time to read on, before taking up more comprehensive works.

Value for money for general interest certainly but not for the student of a particular topic.

D. P. Valler

Newer Engineering Materials. Edited by R. F. Winters. Pp. 140. Macmillan, 1969. Price £3.

This book is based on a short course held in Birmingham in 1967, the purpose of which was to describe the properties of the newer engineering materials and their present uses. There are seven chapters, each written by an author who is an authority in his specialist field.

The first three chapters are concerned with metals. They are headed: Titanium, Zirconium, and Niobium; High-temperature creep resistant materials; Cobalt-base hardfacing alloys. The properties of the metals are well described, and some applications are given. The fact that the authors each unashamedly give information only of their own firms products might be regarded as a criticism. It is possible that the engineer who attempts to use the book to help him solve a particular problem may be little wiser in certain instances. Should he require to know the most suitable material for gas turbine blades and stators for example, he would read in Chapter 2 of the excellence of the nickel based "Nimonic" alloys. In Chapter 3 he would also read of the excellence of the cobalt-based "Stellite" range of alloys for the same purpose.

Chapter 4 deals rather sketchily with fibre reinforced materials, for reasons which are not far to seek. Little information is given about glass reinforced plastics as there is so much available elsewhere. Not much more is given about composites such as boron and carbon with aluminium, as in 1967 evaluation of these materials in depth had scarcely begun.

Chapter 5, under the heading of ceramics, includes glasses and carbon. These materials have a very wide range of applications indeed, not greatly limited by cost, and many advances have been made both in development and application in recent years. It is interesting to note that only three small paragraphs are devoted to silicon nitride. Had the chapter been written two years later, this material would surely have warranted several pages. There is unfortunately little reference to work carried out in the U.S. where space and missile developments have forced the pace for ceramic applications.

In Chapter 6 on "newer polymers", methods of manufacture and commercial applications are described, many of which are 20 years old. Aspects of individual polymers are mentioned rather than full descriptions, and little information is given about recent developments. Had the chapter lived up to its heading, a great deal could have been left out, or simply tabulated, and more description given of the polymers, that have become available in the last two years.

Chapter 7 is about polymers as engineering materials. It treats polymers as a group without reference to individual types, and is apparently written for the engineering designer. Most of the problems in using the materials are no more than broached, and the engineer would find it necessary to use the references given at the end of the chapter to further his design calculations.

This book can confidently be recommended for purchase by a technical library, where it would be accessible to a number of people, who would profit in up-dating their knowledge in a convenient form. The average engineer would find it rather poor value for his own bookshelf, as in a relatively short time the contents will be out of date.

W. Delaney

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